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THE STRATIGRAPHY OF THE "MAIN LIMESTONE" OF THE KIRKUK, BAI HASSAN, AND QARAH CHAUQ DAGH STRUCTURES IN NORTH IRAQ*

By Dr. R. C. VAN BELLEN†

SUMMARY

The "Main Limestone" consists of strata of ?Palæocene, ?Lower Eocene, Middle Eocene, Upper Eocene, Lower Oligocene, Middle Oligocene, and Upper Oligocene age in the area under consideration. The Palæocene and Eocene sequences are controlled by open shoal reefs, whereas the Oligocene deposits are governed by fringing reefs.

INTRODUCTION

THE great Kirkuk oilfield was discovered in 1927. Its local and regional stratigraphy have been dealt with briefly in previous publications by, amongst others, Baker,[5,6,7] Daniel,[10] Henson,[18] Lees,[23,24] and Nicolesco.[28]

This article deals with the Tertiary reservoir of the Kirkuk oilfield and its time equivalents in the nearby Bai Hassan and Qarah Chauq Dagh structures.

A sketch map (Fig 1) shows the topographical setting of the area, and a more detailed map (Fig 2) gives such topographical terms as are used in this article, as well as the structural subdivisions of the anticline involved.

The term "Main Limestone" is in current use to designate the Tertiary reservoir of the Kirkuk field. Its age varies greatly, from perhaps Palæocene to ?Middle Oligocene, along this structure.

This "Main Limestone" underlies the Lower Fars formation (Pilgrim, SW. Persia, 1908), which is composed of alternating red and blue clays, siltstone, gypsum or anhydrite, salt, and limestone in varying proportions. The base of this Lower Fars formation is formed by a conglomerate—the so-called Basal Fars conglomerate. This straddles an erosional gap, the amplitude of which increases from south-east to north-west.

Since its discovery the producing formation of the Kirkuk field has always been recognized as a reef and shoal deposit with lithological subdivisions which obviously affect the distribution and production of oil. Detailed stratigraphical, petrological, and palæontological studies were consequently undertaken on some 20,000 thin sections representing some 45,000 ft of borehole. This study was extended to adjacent areas, the Qarah Chauq Dagh structure and the Bai Hassan structure, in order to gain a better insight in the stratigraphy, the reservoir characteristics, and the areal distribution of this "Main Limestone."

Publication of the results of this investigation at the present time is appropriate in view of the current interest in reef-controlled reservoirs throughout the world.

All three structures are elongated anticlines. That of Kirkuk is about 60 miles long, with an axis running

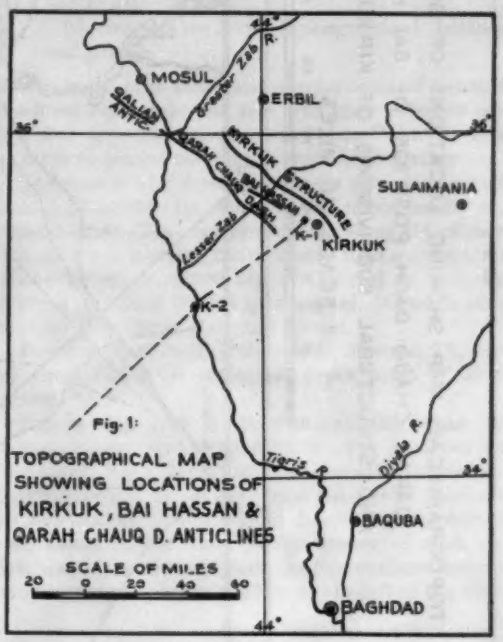

Fig. 1: TOPOGRAPHICAL MAP SHOWING LOCATIONS OF KIRKUK, BAI HASSAN & QARAH CHAUQ D. ANTICLINES

in a north-western–south-eastern direction. This anticline is divided into three domes by two saddles: from north-west to south-east the Khurmala dome, the Dibega saddle, the Avanah dome, the Amshe saddle, and the Baba dome. The south-eastern plunge of the Baba dome is known as the Tarjil plunge.

* MS received 1 December 1955.

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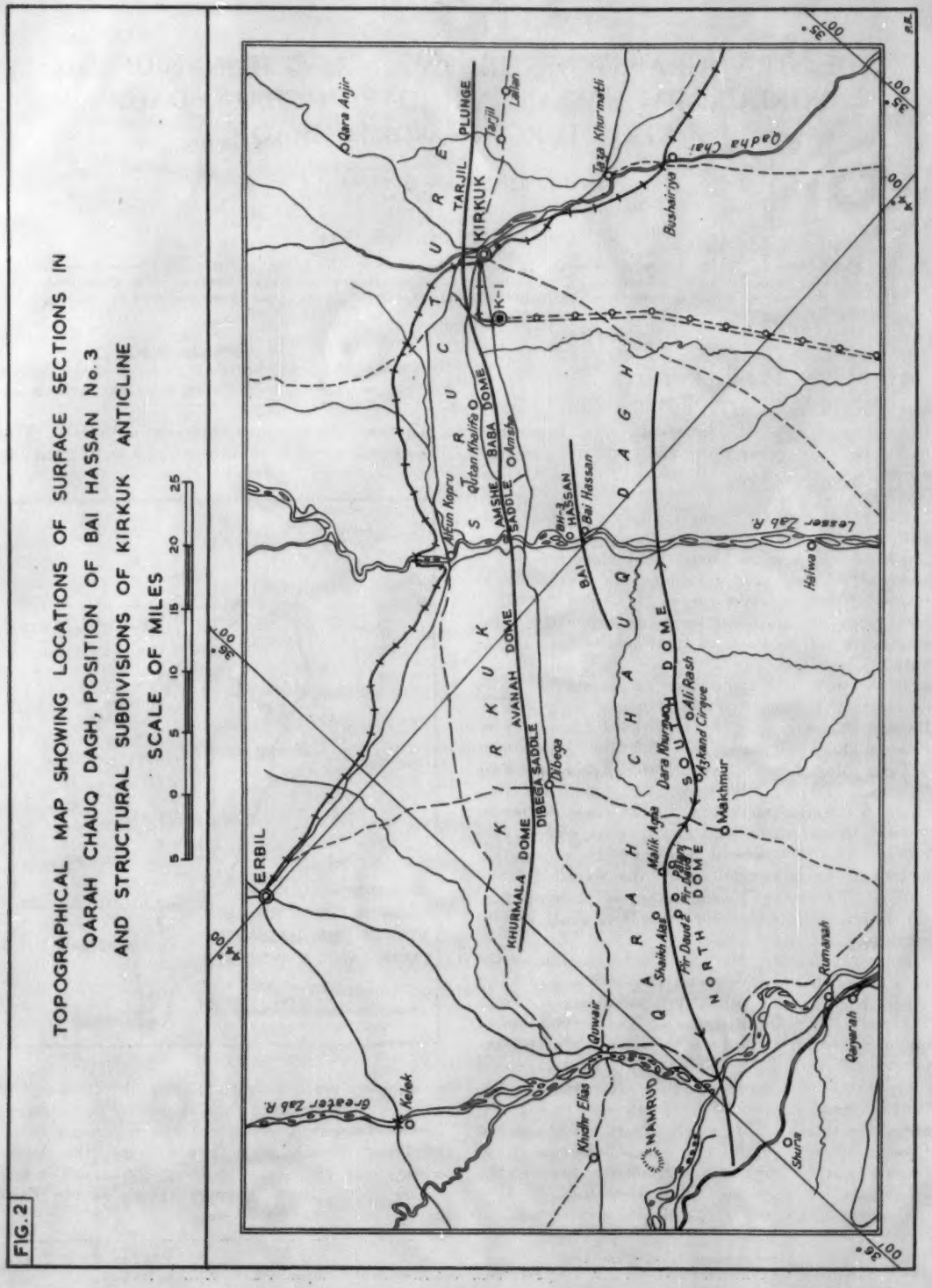
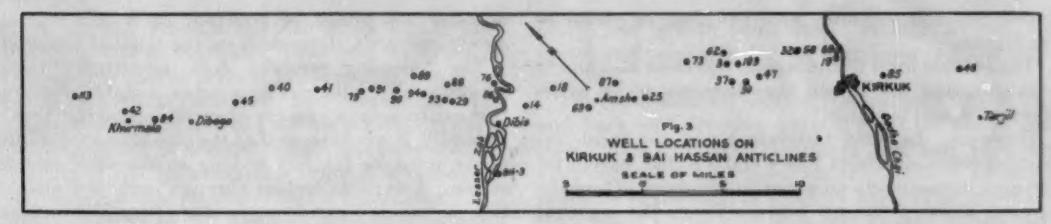


FIG. 2

TOPOGRAPHICAL MAP SHOWING LOCATIONS OF SURFACE SECTIONS IN QARAH CHAUQ DAGH, POSITION OF BAI HASSAN No. 3 AND STRUCTURAL SUBDIVISIONS OF KIRKUK ANTICLINE



The position of the wells mentioned in the text is shown in Fig 3, the more important ones also appear in Fig 33.

The Qarah Chauq Dagh structure has an axis roughly parallel to the one of Kirkuk, and is located about 12 miles south-west of it. Two domes, the northern and the southern, are separated by a saddle, the Makhmur saddle. The Lower Fars cover, which prevents surface study of the " Main Limestone " of Kirkuk, has been eroded off this anticline, leaving part of the " Main Limestone " exposed. The location of the surface sections of this structure which have been mentioned in the text can be found in Figs 2 and 33.

Finally, the Bai Hassan anticline, again roughly parallel to the Kirkuk anticline, runs about halfway between Qarah Chauq Dagh and the Kirkuk structure.

SOME THEORETICAL CONSIDERATIONS

The subject of the influence of transgressions and regressions on the stratigraphy of reef-controlled sediments has been touched upon rather briefly by Henson,[18] Link,[26] and Cloud,[9] amongst others.

Systematic theoretical inquiry into the processes involved and the results obtained, however, had not yet been embarked upon.

It is necessary to set down the author's views on these matters, as the conclusions reached are pertinent to the problems met with in the explanation of the stratigraphy of the " Main Limestone."

The existence of a shelf, either slowly sloping seawards or horizontal, is assumed in all cases, whereas climatic conditions, supply of larvæ, etc., have been considered as constant.

There are thus two interplaying factors : speed of reef growth and change of sea-level. The last factor can be split into three separate ones : rise of sea-level, subsidence of sea-level, and constancy of sea-level. Combination of all these factors gives the following possibilities :

(*a*) sea-level constant;
(*b*) rise of sea-level (transgression)—
  (i) reef growth outbalances transgression,
  (ii) reef growth does not keep pace with transgression;
(*c*) subsidence of sea-level (regression)—
  (i) reef growth outbalances regression,
  (ii) reef growth does not keep pace with regression;
(*d*) subsidence of sea-level (regression) balances reef growth;
(*e*) rise of sea-level (transgression) balances reef growth.

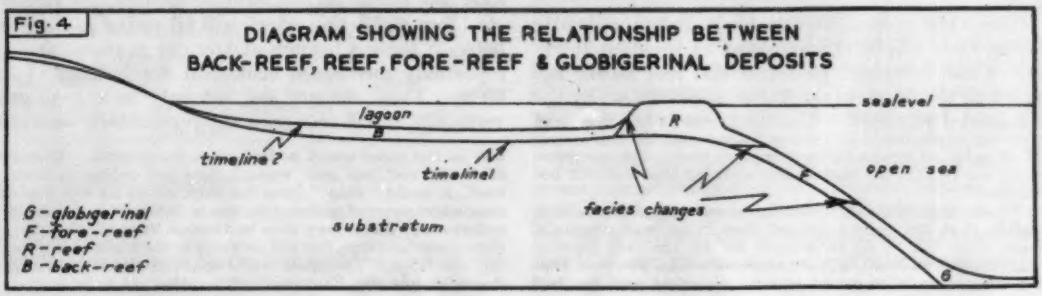
The basic idea that, under conditions of constant sea-level—case (*a*)—the reef will grow over its own fore-reef deposits was known before,[18] but it is of interest to pursue the matter somewhat further.

The reason why a reef, left to its own devices, will indeed grow over its own fore-reef needs hardly any explanation. The reef grows best along its offshore rim, where it receives continuously food, oxygen, etc. These factors occur on top of the reef as well, but vertical growth is limited by sea-level. Growth along that outside rim is therefore fastest.

Down-slope growth of the reef is, moreover, limited by the well-known ecological depth limit of 50–60 metres.[21, p. 417.]

Figs 4 and 5 show diagrammatically what will happen under stable conditions. Fig 4 shows the first stage, Fig 5 the result after a number of stages.

Whilst a reef grows seawards, patches of dead reef are left behind. Solution and decay, loss of cohesion, etc., result in the slow disappearance of such reef patches. It is obvious that, the longer those destructive forces can operate, the less will be left of the aban-



doned reef and the more area can thus be added to the lagoon.

The outside limit of the lagoon therefore also moves seawards, and the lagoon thus becomes wider as its shoreward side is stable.*

However, the most interesting and the most important conclusion from Figs 4 and 5 is that, except for the area immediately adjacent to the shore, where the upward slope of the sea bottom forces the lagoonal sediments to become thinner, the combined thicknesses of reef plus back-reef will remain virtually constant.

It is equally interesting to find that this combined thickness is strongly influenced by the above-mentioned ecological depth limit, which puts a maximum to it of 50–60 m (165–200 ft).†

The thickness of the fore-reef deposits is completely dependent on the configuration of the sea bottom. Its top should be reasonably horizontal, however, dependent as it is on the 50–60 m depth.

In the case that the sea bottom is a level shelf, the thickness of the fore-reef deposits will be constant over distances dependent on the width of the shelf and the duration of stable conditions.

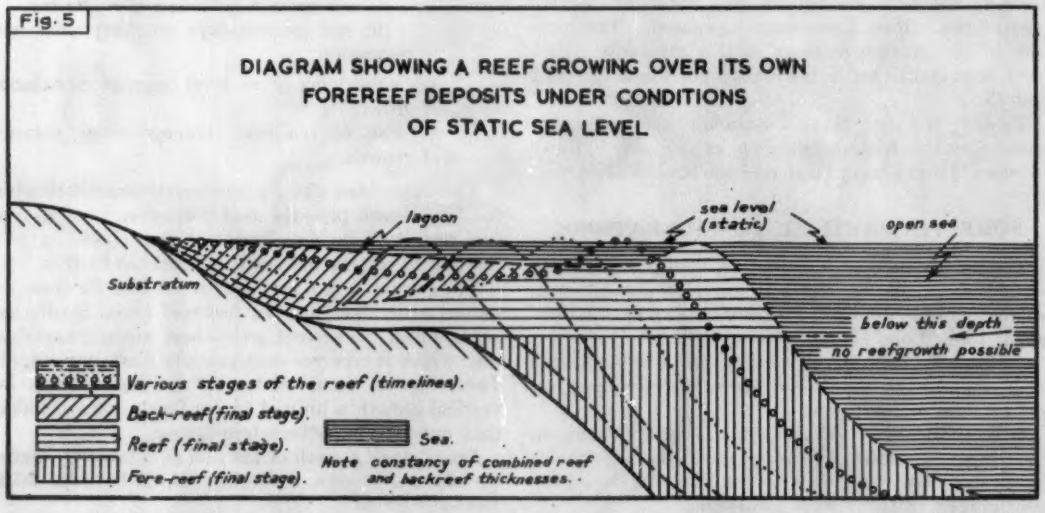
If the sea bottom slopes gently, increase of thickness of the fore-reef sediments seawards must be anticipated.

Thus, a reef growing on a stable horizontal or gently sloping shelf will be characterized by constant thickness of the combined back-reef and reef facies, not exceeding the 50–60 m thickness maximum set by the ecological depth limit. The thickness of the fore-reef deposits will either be constant or it will increase slowly seawards, dependent on the slope of the shelf.

The foregoing remarks deal, admittedly rather schematically, with reef growing on a stable platform. One can imagine a number of variations on this theme. Basically, it would seem that the conditions mentioned above must be fulfilled as long as the shelf remains stable. A vertical section through such reef association or "cycle" can be understood from Fig 5. From top to bottom the following is found:

(top) back-reef
reef
fore-reef
(bottom) off-shore sediments

The next stage in the discussion is the examination of the result of reef growth with rising sea-level, on a subsiding shelf. Two possibilities must be distinguished: reef growth outbalancing the rise of sea-level and reef growth not keeping pace with such rise.



In the case of a transgression associated with reef growth which is more than strong enough to balance rising sea-level (case (*b*/i)), the configuration of the sea bottom is of prime importance. A slowly sloping or sub-horizontal shelf is assumed.

The reef will then first of all grow vertically upwards following the rising sea-level. Secondly, the reef will shed fore-reef debris, which will fill up the gap existing between the sea bottom at any one moment and the repeatedly mentioned ecological depth limit of 50–60 m. Thus, the reef will not only be able to grow vertically, it will also grow sub-horizontally seawards.

* It is by no means claimed that no reef knolls can grow behind the reef, in the lagoon, but a proper reef wall will not be formed.

† If the reef originally grew on a submarine ridge, it is possible that the lagoon behind that ridge was originally deeper than the 50–60 m allowed for by the reef growing organisms themselves. It seems inconceivable, however, that such submarine ridge would proceed seawards with the reef and at the same speed as its horizontal growth. Therefore, after the reef has shed enough fore-reef debris in front of itself, it could "step" from the ridge on to its own fore-reef debris and proceed growing seawards, followed by its lagoonal sediments. These may thus be thicker than 50–60 m behind the submarine ridge, but will decrease in thickness on approaching the ridge. Thickness will remain constant seawards of the ridge (see also Kuenen [21, p. 480]).

It will thereby increase the size of its lagoon horizontally as well as vertically, grow over its own fore-reef deposits, and in general behave quite like a reef growing on a stable platform. But, because the transgression enables the reef to grow vertically, the depth of the lagoon will be affected to such an extent that the thickness of the back-reef sediments will exceed the limits imposed upon it under stable conditions.

The thickness of the fore-reef sediments, whether the sea bottom is horizontal or slowly sloping, will increase seawards over a short distance, subsequently tailing off into off-shore sediments.

A vertical section through this kind of reef association will obviously be quite like the one produced by development of a reef on a stable shelf, except for the thickness to be expected :

(top)	back-reef
	reef
	fore-reef
(bottom)	off-shore sediments

Another possibility, falling within the same general conditions of reef growth outbalancing the transgression, is that the reef cannot produce enough fore-reef debris to fill up the gap between sea bottom and ecological depth limit. Horizontal growth being limited by lack of suitable environment, a high reef wall will be found. Fore-reef sediments will be thick immediately in front of the reef, but will peter out rapidly seawards. Movement of the reef will not be possible, and conditions must therefore centre on vertical growth. Lagoonal depth will increase. As long as the reef does not move horizontally, the different facies will remain in their original position and increase their thicknesses *in situ*. The stratigraphy in any particular vertical section should meet therefore only one facies, dependent on where the section is located.

The third case to deal with is (*b*/ii), where rise of sea-level outbalances reef growth.

Because of the rise of sea-level, the 50–60 m depth line shifts continuously shorewards, and the reef will therefore tend to follow it, covering former back-reef deposits and trailing behind it fore-reef deposits, which cover older drowned reef and back-reef. The thickness distribution is in all cases completely dependent on the configuration of the sea bottom and the relative speed of the transgression. Whereas, however, in the former cases vertical successions show off-shore deposits at the base, passing upwards via fore-reef to reef–back-reef deposits at the top, the succession in the case here considered shows the reverse, namely

(top)	off-shore sediments
	fore-reef
	reef
(bottom)	back-reef

This characteristic is enough to distinguish this case from any others.

There remains now to be discussed the case of reef growth under regressive conditions. The first possibility, reef growth being strong enough to seek out places still available for settling (case (*c*/i)) is dealt with first.

The regression will destroy continuously former reef and back-reef deposits when they come above sea-level. The extent of remaining reef and back-reef after regression has ceased should therefore be small, probably in the form of a narrow belt. The combined thicknesses of reef and back-reef in that narrow belt should never exceed 50–60 m. The thickness of the fore-reef sediments is completely dependent on the configuration of the sea bottom.

There are some interesting points in this case which merit attention. Whatever the slope of the sea bottom, the addition of fore-reef debris will tend to steepen it. That means that at any one moment the horizontal distance between the zero depth line and the 50–60 m depth line will be smaller than some time before and larger than some time later. Consequently, the available area for actual reef building will decrease with progressive regression. At the same time, regression will bring former reef deposits above sea-level, whereby they will be destroyed.

Since, however, the area of reef growth becomes narrower, the supply of detritus will grow smaller, and this adds to the ultimate narrowness of the reef belt, because at times not enough debris will be available to reduce the depth of the sea bottom to reef building level.

It seems, therefore, that if regression lasts long enough, the reef, although growing vigorously, cannot survive as an effective reef wall.

The result must therefore be that the ultimate association will consist of a narrow reef belt—if it managed to survive—backed by an equally narrow back-reef belt (former back-reef being brought above sea-level continuously by the regression) and with a sheet of fore-reef sediments in front of it.

A vertical succession would yield the following :

(top)	back-reef
	reef
	fore-reef
(bottom)	off-shore sediments

This is substantially the same succession as in the case of reef growth on a stable shelf, but with the most important difference of the narrowness of back-reef and reef belts and the absence of any area of constant back-reef and reef thickness.

In the last case of interest (*c*/ii)), reef growth cannot keep up with regression, and the existing reef is doomed to die without migration. If it migrates at all it will migrate seawards. The depth of the lagoon will become continuously shallower, and back-reef deposits will therefore decrease in thickness seawards.

There are still cases (*d*) and (*e*) to be discussed. It seems inconceivable that such delicate balance would persist through any length of time. And in any case the result of (*d*) would be substantially the same as in case (*b*/i), and the result of (*e*) would be very similar to that of case (*c*/i).

It is now possible to replace this entire discussion by the details given in Table I.

TABLE I

	Thickness		Vertical succession
	Back-reef plus reef	Fore-reef	
Shelf stable	Constant over large distances, total less than 50–60 m or equal to that amount	Constant or slowly increasing seawards	Back-reef Reef Fore-reef Off-shore sediments
Rise of sea-level outbalanced by reef growth	Increasing towards the sea, to total of more than 50 to 60 m	Increasing seawards or constant, but always thicker than under stable conditions	Back-reef Reef Fore-reef Off-shore sediments
Rise of sea-level outbalances reef growth	?	?	Off-shore sediments Fore-reef Reef Back-reef
Subsidence of sea-level outbalanced by reef growth	Narrow belt, thickness increases from zero near shore to maximum of 50–60 m immediately behind reef	Decreases seawards	Back-reef Reef Fore-reef Off-shore sediments
Subsidence of sea-level outbalances reef growth	Decreases rapidly seawards, while subsidence overcomes reef growth	Depends on relative strength of subsidence	Back-reef Reef Fore reef Off-shore sediments

It will be seen from Table I that in four cases the vertical succession strongly suggests active regression, but in two cases the suggestions are false. In all these cases, near-shore sediments occur on top of off-shore ones. One case concerns the situation under stable conditions, and in this case the suggestion of regression is therefore a false one. A second case is the one arising from a reef growing strongly under conditions of a slow rise of sea-level. Again, the suggestion is a false one. The third case offers a genuine suggestion of regression: strong reef growth under conditions of slow subsidence of sea-level. Finally, the fourth case, subsidence of sea-level outbalancing reef growth again offers a genuine suggestion. In this case, however, it seems highly doubtful whether migration of the reef will ever take place on any but a limited scale.

Admittedly, there are other distinguishing characteristics, but nevertheless the terminology of Henson and Link, calling all reefs resulting from transgression (rise of sea-level) transgressive reefs, and all reefs resulting from subsidence of sea-level (regression) regressive reefs, cannot hold any more and would lead to confusion. Indeed, Henson defines his terms properly and reserves them, morphologically, for reefs resulting from "movement respectively towards and away from the adjacent land area," [18, p. 233, note 13] but the terms nevertheless suggest reason for origin as well. It has been decided therefore to introduce a different terminology, which should not lead to confusion, by omitting all terms referring advertently or inadvertently to origin.

Thus, reef formations resulting from reef migration towards the sea are called "emigrating reefs," whereas reef formations resulting from migration of reefs towards the land are termed "immigrating reefs."

At the same time, it has been considered of importance to restrict the terms "back-reef" and "fore-reef" to strata which are known to have been governed in deposition by, and separated by, a proper living organic reef wall. For similar facies where existence of such reef wall could not be proved the terms "lagoonal" and "shoal" are used.

There is to some extent a difference between the two associations. A proper organic reef does not allow a great deal of interfingering between back-reef and fore-reef facies. Their separation is therefore sharp and fairly easily detectable. Such is not the case with shoal and lagoonal deposits. Frequent interfingering will occur, and the existence of the two facies is probably due only to some sort of ridge or to a number of small reef knolls (Henson's open shoal reef). Another difference is that such a barrier does not grow actively and is probably not limited in thickness by ecology, etc.

PALÆOCENE AND EOCENE OF THE KIRKUK STRUCTURE

Introductory Remarks. Although the theories set out in the foregoing section have but little bearing on the stratigraphy of the Palæocene and Eocene, it has been considered desirable not to depart from the traditional practice of dealing with stratigraphy in order of deposition.

A number of wells have encountered Eocene and Palæocene below Lower Fars or Oligocene. But only one well, K-109, has actually penetrated both and reached into the Upper Cretaceous.

Knowledge of the sediments of the two time units under consideration is consequently limited. But through the agency of inter- and extrapolation on the basis of regional knowledge, an understandable though rather sketchy picture can be assembled.

The Palæocene. In the north-west, a chemical limestone which, though thoroughly recrystallized, still shows numerous indications of having been deposited in a lagoon (miliolids, oolites) occurs in a number of wells (K-40, K-42, K-113). This limestone invariably contains scattered sand-size fragments of radiolarites, green rocks, chert, and quartz. The detritals grade downwards into actual conglomerates. Thicknesses can be found in Fig 9. Plate IVA shows a thin section of this facies.

There are no age-indicative fossils, but correlation is assumed with the Kolosh ("flysch") formation of the mountain sections (publication pending). This is of Palæocene age.

Further, towards the south-east, subsurface evidence of Palæocene age is limited to that provided by a single well which penetrates Lower Eocene. This is K-109, which shows a silty argillaceous globigerinal marl. The fauna appears on the range chart (Fig 6), which also gives the thickness. Plate IVC shows a comparable facies.

Although it seems fairly evident that the chemical facies must have been separated from the basinal

facies by either a topographical or an organic barrier, no evidence of such a barrier has yet been found within the Kirkuk field, so that its existence must remain an assumption.

The Lower Eocene. Sedimentation during this period was very similar to what is known of the Palæocene. Again, in the north-west, in wells K-40, K-42, K-113, a lagoonal chemical limestone (miliolids, oolites) occurs with fine quartz, silt, and pyrite this time (see Plate IVB).

It is possible that this limestone can be correlated with the Gercus formation [31] of the mountain sections (definition in press), which is of Lower Eocene age.

Additional evidence for a Lower Eocene age of these sediments is the fact that they are separated from overlying proved Middle Eocene by a transgression (see below). This probably low Middle Eocene or high Lower Eocene transgression is known practically throughout the Middle East, and any post-Cretaceous rocks found to underlie it are likely to be of Lower Eocene age.

Farther towards the south-east Lower Eocene is found in off-shore facies (K-14, K-19, K-109) with a fauna as shown in Fig 6 (see Plate IVC).

Total penetration has only been obtained in K-109, so that the actual thickness of Lower Eocene in off-shore facies is known only in that area.

Though here again the evidence calls for the existence of a topographical or organic barrier between the chemical lagoonal facies and the globigerinal off-shore facies, no such barrier has been found, as no well has penetrated deep enough in the crucial area. It is known that somewhat more to the north-west, along the direction of the Lower Eocene facies belts, shallow open sea facies of that age does occur in Jebel Qalian (Fig 1).

The Middle Eocene. Sediments of this age are known from other wells, and consequently matters become somewhat more complicated.

As mentioned above, there is evidence of Middle Eocene transgression over ?Lower Eocene in the north-west. Middle Eocene shoal facies covers Lower Eocene lagoonal chemical limestone in K-40, K-42, and K-113 (for thicknesses see Fig 9).

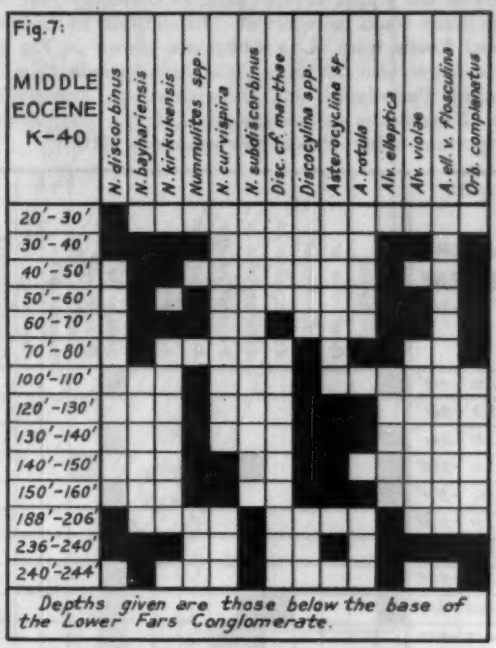
Such superposition is impossible without a transgression, which must be invoked to explain the immigration of the various facies realms.

The shoal facies of the Middle Eocene in the north-west shows lagoonal fossils amidst the nummulites and discocyclinids, evidencing lagoonal inroads upon the shoal realm (Plate VA).

Further to the south-east the shoal facies gradually loses its lagoonal elements (Plate VB), and south-east of the Lesser Zab it passes laterally into globigerinal marl (Plate VC) as found in all wells which are deep enough in the Amshe saddle and the Baba dome. One or more shoal intercalations persist in this marl.

The fauna of this Middle Eocene in shoal facies appears on the range chart for K-109, from the shoal tongue between 785 ft and 855 ft depth BLFC * (below Lower Fars conglomerate), (Fig 6).

An additional example of this fauna can be found on the range chart for K-40, which is based on data provided by T. F. Grimsdale (Fig 7), but which does not cover the entire Middle Eocene, part of it being too recrystallized for fossil determination.



It should be mentioned that no single complete section of Middle Eocene in shoal facies is known. In some wells its upper part has been removed by the Lower Fars transgression, in other wells the bit did not go deep enough to penetrate it entirely.

The Upper Eocene. What has been said in the preceding paragraph also holds true for the Upper Eocene. It can be found in shoal facies in a few wells in the north-west (Plate VB), but only K-29 reached into the Middle Eocene. In that well, however, recrystallization has made the recording of fossils very unsatisfactory. Moreover, the top of the Upper Eocene was truncated by erosion prior to deposition of the Lower Fars. Again, there are some intercalations of miliolid limestone which demonstrate lagoonal influence. But no truly representative lagoonal sediments of either Middle or Upper Eocene age have been found in the Kirkuk structure. It is reasonable to suppose that these have been removed by the Lower Fars transgression if they ever were present.

South-east of the Lesser Zab, Upper Eocene occurs in globigerinal facies (Plate VC). There is little doubt that, during the Upper Eocene, regression compelled the various facies realms to emigrate, as in K-14 shoal

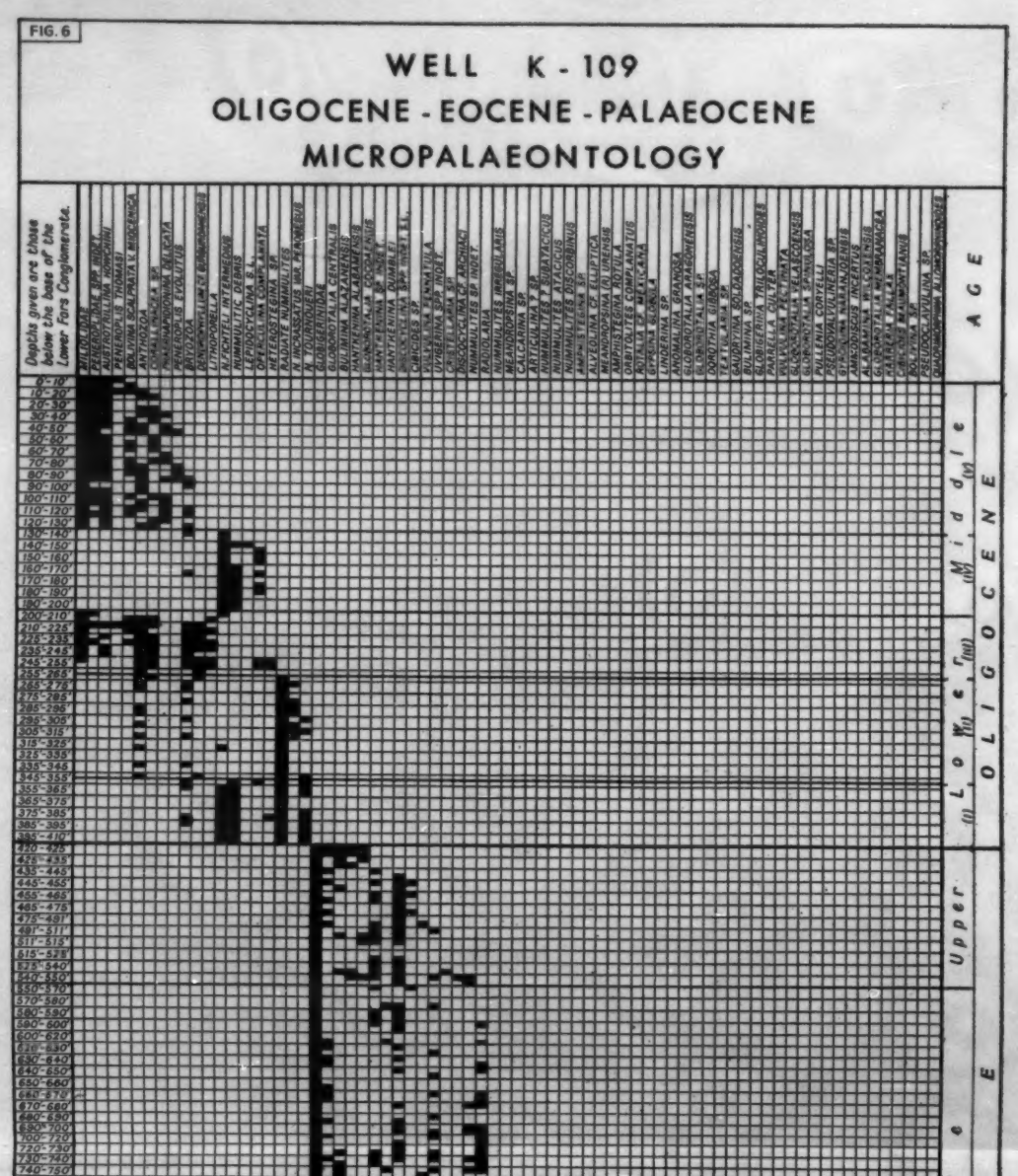
* All quoted depths in this article have been calculated from the base of the Lower Fars downwards.

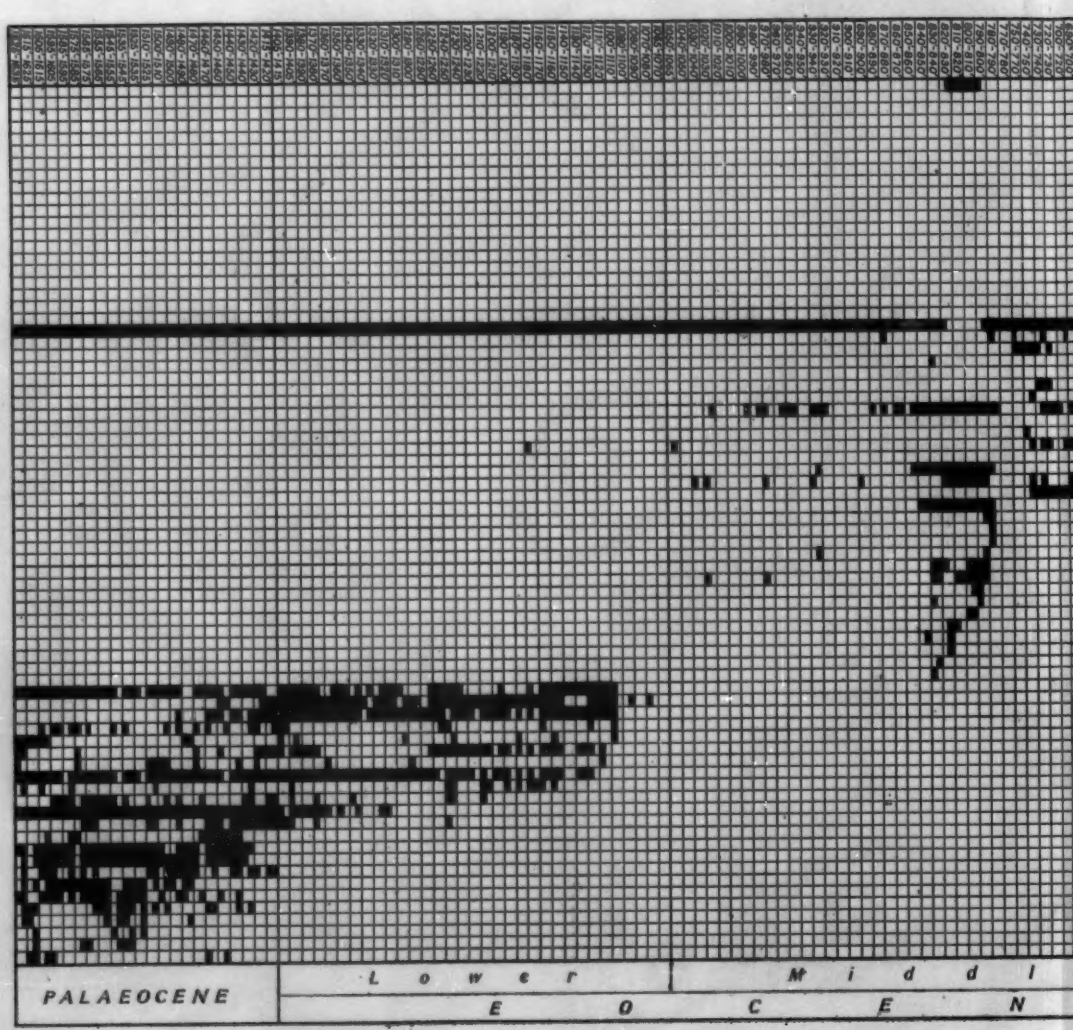
FIG. 6

WELL K - 109

OLIGOCENE - EOCENE - PALAEOCENE

MICROPALAEONTOLOGY

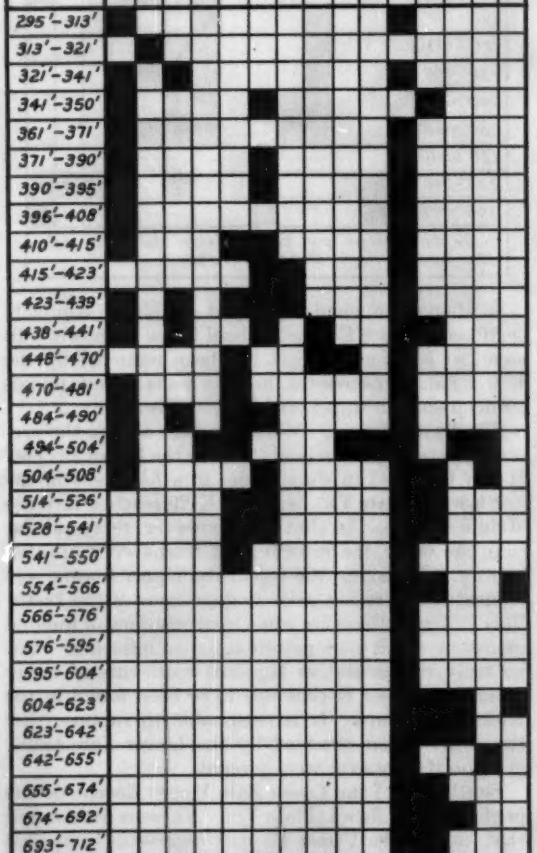



PALAEOCENE
Lower
Middl
EOCEN

fossils of Upper Eocene age occur resting on off-shore fossils of the same age at about 526 ft BLFC (Fig 8 gives a faunal range chart for the Upper Eocene of this well). Off-shore facies of Upper Eocene age has also been found in other wells, and Fig 6 gives a more detailed example of the fauna in this facies. It should be remarked that a fault cuts out the upper part of the Upper Eocene here, so that only part of the fauna could be recorded. In addition to the few shoal fossils from K-14 which are shown in Fig 8, this facies also contains *Asterigerina rotula* (Kaufmann), *Cycloclypeus* sp., *Dictyoconus* sp., *Eorupertia* sp., *Nummulites incrassatus* de la Harpe, and, as an important index, *Pellatispira madaraszi* (Htk.).

Fig: 8:

UPPER EOCENE K-14



Depths given are those below the base of the Lower Fars Conglomerate.

No range chart has been appended from the north-western wells, as recrystallization in practically all Avanah and Khurmala wells hampers observation severely and makes the examination of continuous suites of samples impossible. Thicknesses of Upper Eocene in various facies in the more important wells are shown in Fig 9.

There is apparently a substantial difference between the conditions under which the Middle and Upper Eocene were deposited and those which governed Palæocene and Lower Eocene. In the last case, no trace of mixing can be found between lagoonal and shoal facies, whereas in Middle and Upper Eocene such mixing indeed occurs.

Though there is no doubt that some sort of separation between lagoon and shoal must have existed both in the Middle and in the Upper Eocene, it seems that this barrier of sorts was by no means as effective as the one which separated the lagoonal chemical facies from its assumed shoal companion during Palæocene and Lower Eocene times.

It is reasonable to suppose that it was actually the low Middle Eocene transgression which destroyed the Lower Eocene barrier and replaced it by an inefficient part-barrier, an example, probably, of Henson's "open shoal reef." [18]

The presence of a good deal of interfingering between shoal and lagoonal facies makes the problem of presenting a section across the Eocene and Palæocene a very hazardous one. It has nevertheless been considered of interest to reproduce such a section for this period, as a parallel to the better controlled one which is found below, for the Oligocene in this structure. Owing to the difficulties mentioned above, however, this section cannot be a cross-facies section. It has been assumed that facies lines (defined as the limit between two facies belts) are parallel to time boundaries.

The section has therefore been drawn perpendicularly to the limit between Upper and Middle Eocene below the Lower Fars cover (see also Fig 33). Owing to the curvature of this limit, the ordinary procedure of perpendicular projection could not be followed, and the points of observation have therefore had to be projected parallel to this Upper–Middle Eocene limit. The result is seen in Fig 9.

There is no doubt about the serious defects of this section. It is greatly inaccurate; there exists near-certainty that the section is not actually perpendicular to facies lines. It has proved impossible to show the numerous interdigitations between the various facies. It is also highly doubtful whether the limit between Palæocene and Lower Eocene is parallel to that between Upper and Middle Eocene. The section should therefore be considered as strictly schematic (apart from the indicated thicknesses). Owing to the great number of wells which showed only partial penetration of any one unit, only a few wells could be used, and no proper faunal zonation has been attempted.

In spite of these numerous short-comings, the portrayal should have some value, since it gives at least some approach to the actual truth.

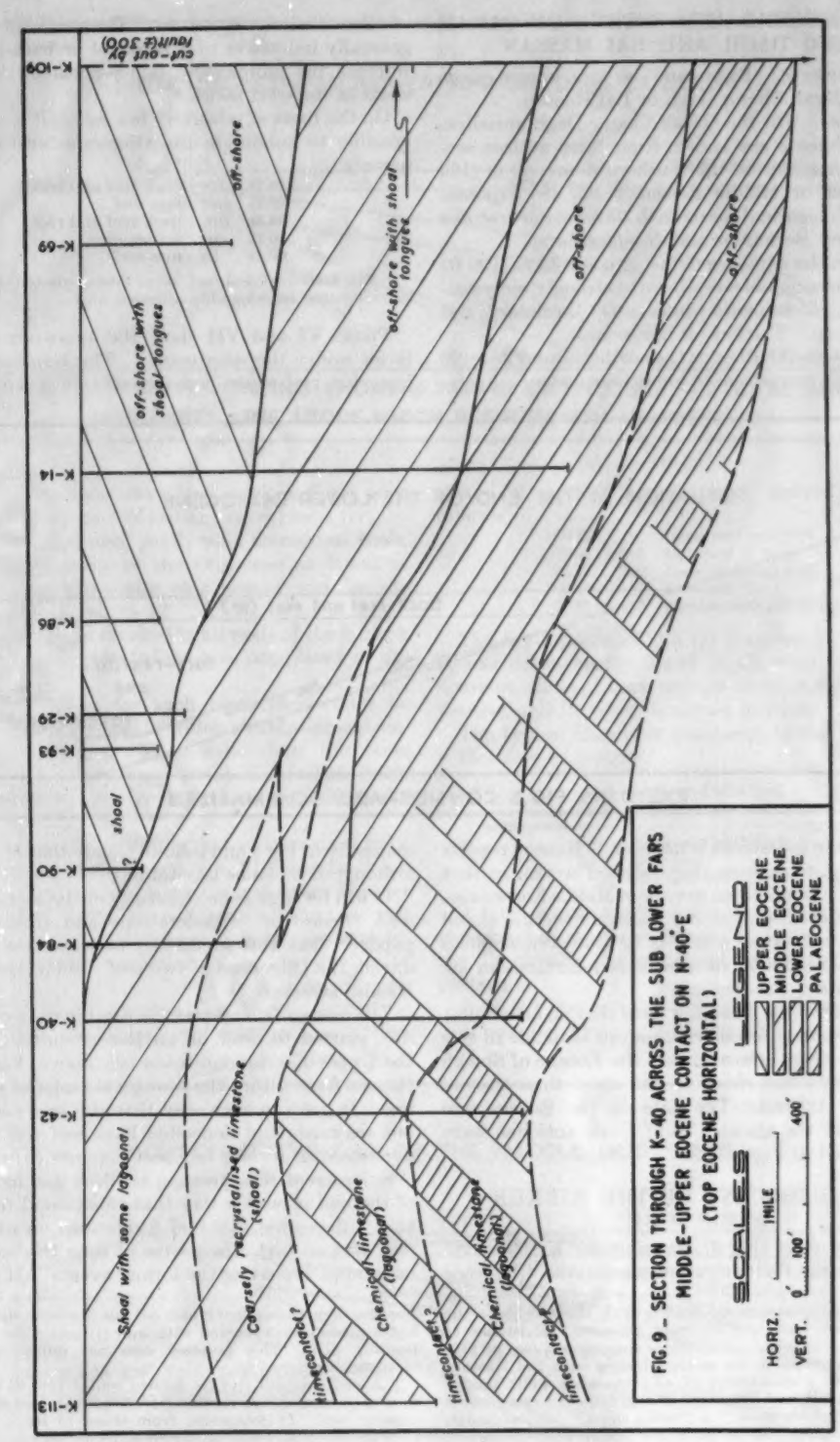


FIG. 9 – SECTION THROUGH K-40 ACROSS THE SUB LOWER FARS MIDDLE–UPPER EOCENE CONTACT ON N-40°E (TOP EOCENE HORIZONTAL)

THE PALÆOCENE AND EOCENE OF QARAH CHAUQ DAGH AND BAI HASSAN

The Palæocene. Palæocene is not known from either the Qarah Chauq Dagh or Bai Hassan.

The Eocene. On the Qarah Chauq Dagh anticline, Eocene sediments are known from three surface sections. At Azkand, on the southern dome, 50 m (165 ft) of Upper or Middle Eocene rocks are exposed. These are globigerinal marls with *Globorotalia centralis* Cushman and Bermudez and *Hantkenina* sp.

Palani, on the northern dome, exposes 32 m (106 ft) of Upper Eocene globigerinal marls, strongly recrystallized, with *Globorotalia cocoaensis* Cushman and *Hantkenina* sp. The base is not seen.

Finally, at Sheikh Alas, on the northern dome 28 m (90 ft) of strongly recrystallized limestones occur. Again, the base of the limestones is not seen. Henson reports *Orbitolites* sp. from here (unpublished work), so that these rocks, in shoal facies, may be of Middle Eocene age.

The well drilled on the Bai Hassan structure ended in the Upper Eocene, which is in globigerinal facies there with *Globorotalia cocoaensis* and *Hantkenina* sp. but penetration was negligible.

It is evident from these few data that no attempt at palæogeographical reconstruction can be made in this area. It is clear, however, that the Eocene of Sheikh Alas was deposited closer to the shore than that of Palani and Azkand. The data on the Eocene and Palæocene of the Qarah Chauq Dagh anticline have been included in Figs 25–28.

THE OLIGOCENE OF THE KIRKUK STRUCTURE

The range chart (Fig 6) drawn up for K-109 serves to illustrate the facies stratigraphy of the Oligocene of the Kirkuk structure. The miliolid fauna is generally indicative of a lagoonal or back-reef facies, whereas the nummulitic fauna normally indicates a shoal or fore-reef facies.*

On the basis of relatively few fossils it is apparently possible to subdivide the Oligocene into five units, namely

130 ft	(v)	back-reef and reef †	
70 ft	(iv)	fore-reef	
60 ft	(iii)	back-reef and reef	
90 ft	(ii)	transitional	(ii/i)
60 ft	(i)	fore-reef	(ii/i)

† The back-reef and reef facies intergrade too complexly to be recognized as mappably-different units.

Plates VI and VII show the appearance of these facies under the microscope. The terminology used here for reef-controlled deposits is given diagrammatically in Fig 4 and follows closely that of Henson,[18] although it includes less detail.‡

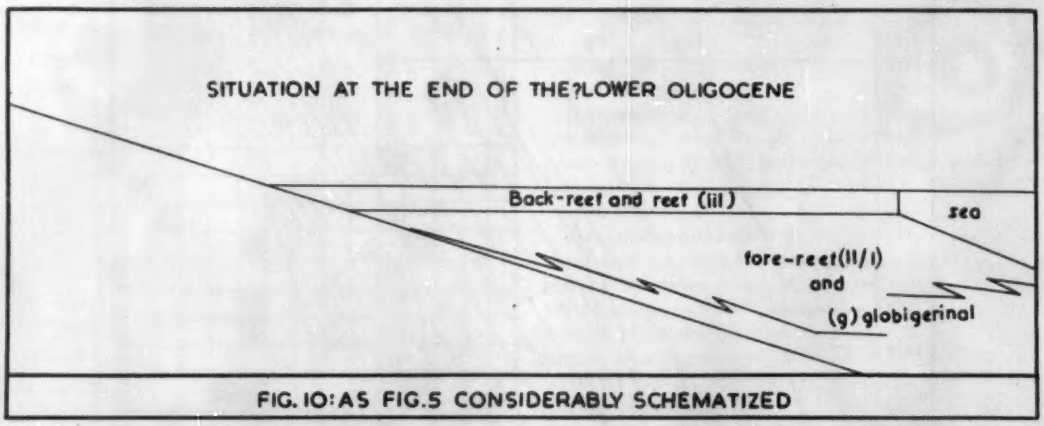


FIG. 10: AS FIG. 5 CONSIDERABLY SCHEMATIZED

It will be clear from the study of the section dealing with theoretical considerations and from Henson's paper [18] that this succession indicates the existence during the Oligocene of two reef "complexes" in the Kirkuk structure.§

The first reef "complex," a combination of (ii/i) and (iii), started to grow on an Eocene substratum after the Upper Eocene regression (see above) had brought the sea floor within the ecological realm of reef building. It grew in such way that the reef itself moved out seawards and deposited back-reef sediments (iii) over its own former fore-reef deposits (ii/i).

Subsequent transgression resulted in a move inland of the reef in such a way that this second reef "complex" deposited fore-reef formations on older back-reef, (iv) on (iii). In course of time this second reef emigrated, repeating the former events. It grew over

* Throughout the sections dealing with the Oligocene the terms back-reef, reef, and fore-reef are used. Existence of an actual reef wall which necessitates these terms (see p. 238) will become apparent in the section dealing with Bai Hassan.

‡ Subsequent examination of all remaining wells taught that it is difficult and often most subjective to recognize a "fore-reef transition zone," a "talus slope," etc., although in some cases there can be no doubt about their existence. For the sake of simplicity unit (ii) has not been differentiated but has been incorporated with unit (i) under the temporary heading (ii/i). This practice does not influence the final interpretation.

§ A reef complex can be defined tentatively as an association of several facies resulting from growth and death of an organic reef. It comprises, from shore to basin, back-reef, reef, fore-reef, and equivalent off-shore facies.

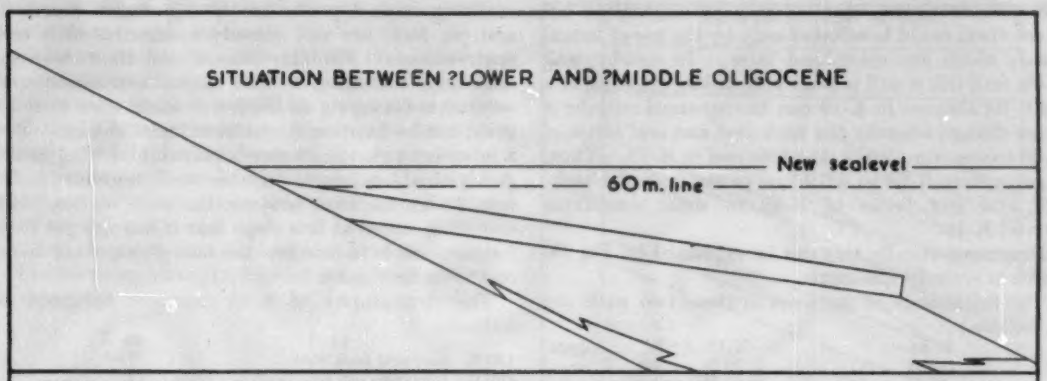


FIG. 11: AS FIG. 10, AFTER TILTING SHOWING THE RESULTING NEW SEALEVEL AND THE 60m. DEPTH LINE ABOVE WHICH REEFGROWTH IS POSSIBLE

its own fore-reef and deposited back-reef (v) once again over those fore-reef sediments, (v) over (iv).

The above is deduced, partly on a theoretical basis, from the stratigraphy of the Oligocene as found in K-109. Diagrammatically this theory can be expressed by Figs 5 and 10–12.

This idea has been checked in all wells of the Kirkuk structure which penetrated or were completed in the Oligocene.

Strong indications for such bipartition could be found in all wells studied in which stratigraphic penetration was sufficient. Most wells show the same succession as K-109 : (v)–(iv)–(iii)–(ii/i). This holds true especially for the wells situated on the Baba dome.

It had been found, however, that an important fault cuts K-109 at approximately 420 ft BLFC and a check was therefore necessary on a nearby well to see whether any part of the Oligocene had been affected by this fault so as to render the sequence of K-109 incomplete.

This suspicion was confirmed by the examination of material of K-37. There, below unit (ii/i) approximately 50 ft of globigerinal post-Eocene limestone occurred, which was termed (*g*) for future easier reference. The K-37 stratigraphy proved to be as follows :

130 ft	(v)	back-reef and reef
70 ft	(iv)	fore-reef
75 ft	(iii)	back-reef and reef
180 ft	(ii/i)	fore-reef
50 ft	(*g*)	globigerinal off-shore

The explanation of unit (*g*) is shown in Figs 10–12. It was subsequently found in all wells of the Baba dome which went deep enough to reach the top of the Eocene, and its facies is shown in Plate VIc.

The typical Oligocene succession in the Baba dome is therefore as follows :

(v) back-reef and reef
(iv) fore-reef
transgression– – – – – – – – – – – – – –transgression
(iii) back-reef and reef
(ii/i) fore-reef
(*g*) globigerinal off-shore

A further examination of wells in the south-easternmost part of the Baba dome (K-19 and K-68) and in the Tarjil area shows a significant variation on this pattern.

In K-19 the entire lower back-reef and reef unit (iii) has disappeared, and the two fore-reefs are in

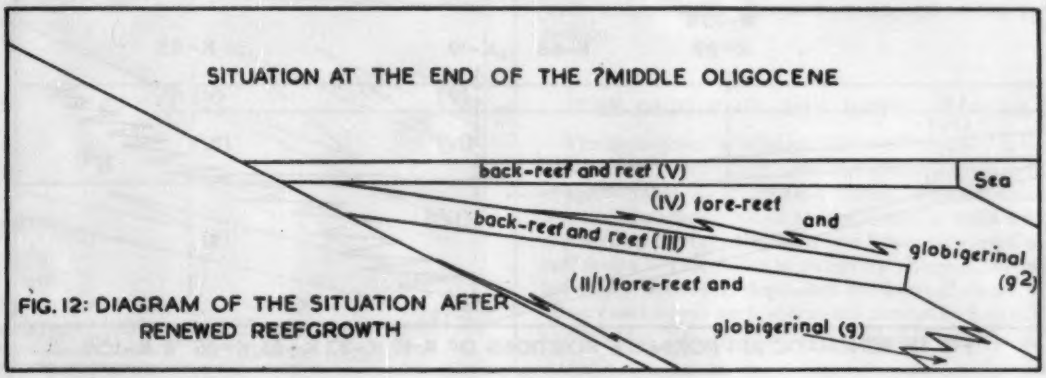


FIG. 12: DIAGRAM OF THE SITUATION AFTER RENEWED REEFGROWTH

direct contact with each other. The separation between them could be effected only by the use of index-fossils which are mentioned later. In nearby well K-68, unit (iii) is still present and, failing evidence of a fault, its absence in K-19 can be explained only by a facies change whereby the back-reef and reef facies of K-68 passes completely into fore-reef in K-19. Thus, in going from K-68 to K-19, one passes from the back-reef and reef facies of K-68 to shoal conditions around K-19.

Diagrammatically this can be explained by Fig 13, which is entirely schematic.

The thicknesses of the units in these two wells are as follows:

K-68		K-19	
110 ft	(v)	70 ft	(v)
95 ft	(iv)	90 ft	(iv)
85 ft	(iii)	425 ft	(iii)
200 ft	(ii/i)	50 ft	(*g*)
40 ft	(*g*)		

In K-85, on the Tarjil plunge, it can be observed that not only has unit (iii) disappeared as a facies unit but also the entire fore-reef (ii/i) has changed into the more off-shore facies (*g*).

Moreover, indications of a change of facies in the upper reef association are given by the presence within unit (iv) of numerous globigerinal streaks or beds (obviously the result of an interfingering in that particular area between fore-reef and globigerinal facies) and by the occurrence of off-shore material (*g*2) below (iv).

The actual correlation, incorporating these logical facies changes is shown in Figs 14 and 15, whilst Fig 13, referred to above, shows diagrammatically the principles behind this correlation.

The result of this somewhat involved facies change between K-19, K-68, and K-85 is, however, that the globigerinal facies of the upper reef association rests on the globigerinal facies of the lower association.

The sensitiveness to environmental changes of any formation directly associated with reefs is great, because the facies "liberties" of the reef itself are very limited.

This results in sharp responses to any environmental change for all facies belonging to such association.

Globigerinal deposits are not, however, sensitive and, in fact, are not directly connected with reef environments. For this reason, the limit between sediments belonging to the upper association and sediments belonging to the lower association in K-85 could not be fixed on the basis of facies change. But a prominent glauconite development, occurring in the globigerinal sediments in this well, without doubt marks here the limit between the two "cycles." It should be noted at this stage that it has not yet been found possible to separate the two globigerinal facies on the basis of index fossils.

The stratigraphy of K-85 can now be given as follows:

130 ft	reef and back-reef
250 ft	fore-reef
510 ft	globigerinal marly limestone (glauconite 290 ft below the top of this unit)

which has been interpreted as:

130 ft	(v)	
250 ft	(iv)	
290 ft	(*g*2)	See Plate VIIc
220 ft	(*g*)	

Further towards the south-east no wells penetrate the higher reef association, and interfingering of units (iv) and (*g*2) becomes more and more important.

The stratigraphy of the reef complex which forms the "Main Limestone" of the Kirkuk structure can now be recapitulated as follows:

	back-reef and reef	(v)
	fore-reef	(iv)
	globigerinal	(*g*2)
transgression		transgression
	back-reef and reef	(iii)
	fore-reef	(ii/i)
	globigerinal	(*g*)

After the stratigraphy of the Main Limestone on the Baba dome and the Tarjil plunge has been elucidated it is now necessary to turn to its development more towards the north-west, in the Amshe and Dibega saddles and the Avanah and Khurmala domes. Fig 13 shows that, passing landwards, globigerinal facies should disappear and change first into a fore-reef facies and subsequently into a reef and back-reef

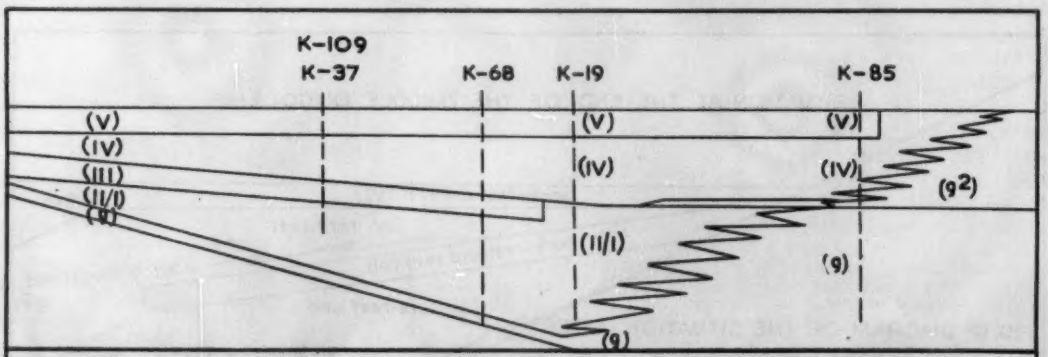


FIG. 13: SCHEMATIC APPROXIMATE POSITIONS OF K-19, K-37, K-68, K-85 & K-109

facies which, on approach to the original coastline, should disappear in its turn.

Wells on the Amshe saddle give the first indications of such facies change. The globigerinal facies disappears between K-69 and K-14, giving place to fore-reef, of the lower association, which rests directly on Eocene. Additional evidence of the approach to a shore line is the decrease in thickness of this fore-reef facies and its actual disappearance between K-86 and K-29 on the south-west flank and between K-18 and K-76 on the north-east flank of the Avanah dome.

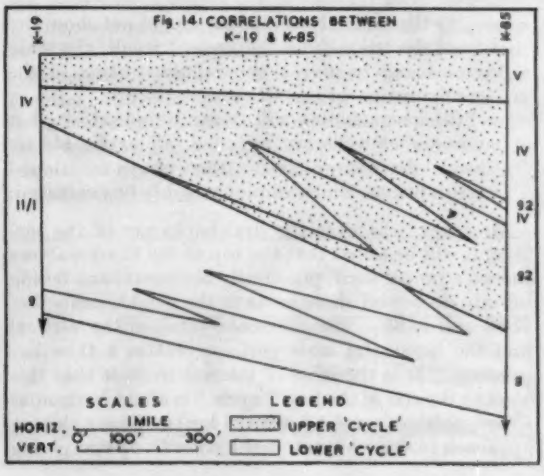
The following stratigraphies can be given in evidence of these statements :

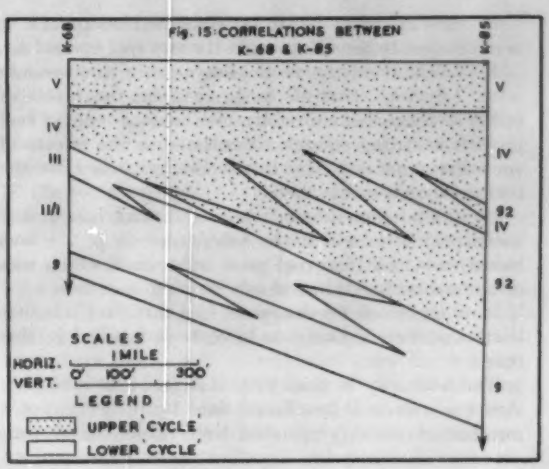
K-69		K-14	
90 ft	(v)	30 ft	(v)
25 ft	(iv)	10 ft	(iv)
30 ft	(iii)	40 ft	(iii)
260 ft	(ii/i)	190 ft	(ii/i)
60 ft	(*g*)	absent	(*g*)

K-86		K-29	
20 ft	(v)	30 ft	(v)
absent	(iv)	absent	(iv)
40 ft	(iii)	40 ft	(iii)
20 ft	(ii/i)	absent	(ii/i)
absent	(*g*)	absent	(*g*)

K-18		K-76	
40 ft	(v)	20 ft	(v)
absent	(iv)	absent	(iv)
40 ft	(iii)	absent	(iii)
86 ft	(ii/i)	absent	(ii/i)
(unbottomed)		absent	(*g*)

In the upper reef association similar indications signal the approach of a shore line towards the north-west. The disappearance of (*g*2) between K-85 and K-19 has already been noted. The fore-reef facies disappears between K-14 and K-86 (see above), on the south-west flank, and between K-87 and K-18, on the north-east flank. The back-reef and reef facies finally disappears altogether north-west of a line running somewhere between K-93 and K-94, on the south-west flank, and somewhere between K-76 and K-88, on the north-east flank. Evidence for these





statements is found below and in stratigraphies already given above.

K-87		K-93	
70 ft	(v)	30 ft	(v)
20 ft	(iv)	absent	(iv)
50 ft	(iii)	35 ft	(iii)
160 ft	(ii/i)	absent	(ii/i)
20 ft	(*g*)	absent	(*g*)

K-94		K-88	
absent	(v)	absent	(v)
absent	(iv)	absent	(iv)
absent	(iii)	absent	(iii)
absent	(ii/i)	absent	(ii/i)
absent	(*g*)	absent	(*g*)

It would appear unnecessary to go into more detail here, but it is of some interest to discuss for a moment the occurrence rather at random of a conglomerate between the two reef associations in a number of wells between K-18 and K-93. These conglomerates are interpreted as clear indications of a transgression of the upper association over the lower one, a third indication therefore, the others being the facies " jump " from back-reef and reef of the lower association to fore-reef of the higher association, and the occurrence of a glauconite bed in K-85. The reason for the preservation of these conglomerates in the wells mentioned is discussed at the end of the next section.

THE ORIGIN OF THE REEF COMPLEX

The transgression between the two " cycles " is thus well marked, especially near the shore, where actual conglomerates occur between them. Further indications of the transgression can be found in wells which reach deep enough to touch the lower back-reef and reef facies. This facies is, in nearly all cases, covered by upper fore-reef, deposited further off-shore. In those cases where such succession cannot be found the explanation lies in the facies changes within each " cycle."

In view of what has been discussed on p. 235, it is of interest to see what origin the two reef cycles had.

It is clear from the vertical succession, the same in both "cycles," that its origin can be the result of either a transgression or a regression, as long as reef growth is strong enough to outbalance the effects of such movements. The third possibility is that the reef grew on a stable shelf.

It will be remembered, however, that one of the assumptions on which the tabulation on p. 238 was based, was that the reef grew on a shelf which was either subhorizontal or slowly sloping seawards.

It is therefore necessary to find out first whether that condition is likely to have been fulfilled in this case.

The best way to deal with this problem is to construct a section across facies lines by projection of a number of suitably situated wells which reach into the Eocene, on a line perpendicular to those facies lines.

The direction of those facies lines must be known first, therefore. This can be estimated in the Avanah area, where the upper back-reef and reef facies pinches out.

Although the actual choice of directions is fairly wide (any direction between any point on the line K-93–K-94 on the south-west flank and any point on the line K-88–K-76 on the north-east flank, see p. 245), it is obvious from thickness distributions that a direction approximately N-120°-E is most likely to be correct in the Avanah area. It will be seen below that a very similar direction can be deduced from facies and thickness comparisons between Qarah Chauq Dagh, Bai Hassan, and Kirkuk.

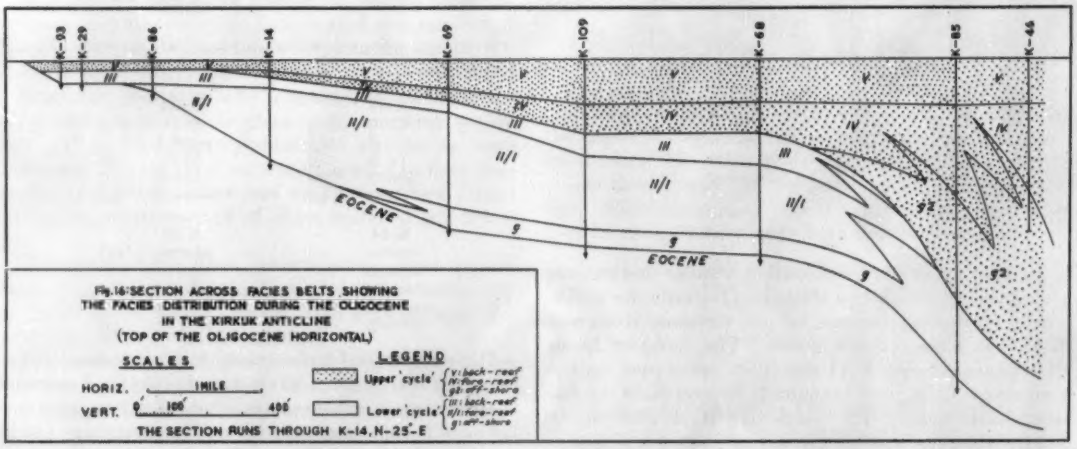
However, if the reconstruction is tried on the basis of this N-120°-E direction, in areas farther to the south-east, it becomes obvious that it leads to false results. A N-110°-E direction has to be adopted to get a reasonable picture in the Amshe–Baba–Tarjil area. Somewhere around the Lesser Zab therefore a swing in the facies lines from N-120°-E to N-110°-E should take place.

The section across facies lines can now be obtained by projecting a number of wells parallel to those facies lines on a line of section perpendicular to them. The result, Fig 16, is perfectly straightforward, but it should not be considered more than only approximately correct, as there are several assumptions without proof incorporated in the design. Some of them are:

(i) the facies lines are straight (a most improbable hypothesis);

(ii) the facies lines during the lower "cycle" run strictly parallel to those of the upper "cycle" (an equally improbable hypothesis);

(iii) the facies direction N-110°-E is correct. It is known that this is not true in the Avanah area, and the indicated curvature is only approximate.


EOCENE
EOCENE
Fig.16: SECTION ACROSS FACIES BELTS SHOWING THE FACIES DISTRIBUTION DURING THE OLIGOCENE IN THE KIRKUK ANTICLINE (TOP OF THE OLIGOCENE HORIZONTAL)
SCALES
HORIZ. 1 MILE
VERT. 0 100' 400'
LEGEND
Upper 'cycle'
Lower 'cycle'
THE SECTION RUNS THROUGH K-14, N-25°-E

Moreover, only a small number of the existing wells have been used in the construction, for several reasons, amongst which the following are of some importance:

(i) theoretically, additions should not show any great deviation from the present result, the main idea being to give a general illustration of the configuration of the Oligocene;

(ii) irregularities will occur if indeed a great number of wells are included, all explicable by local departures from the above-mentioned assumptions, which cannot possibly be evaluated.

However, whatever the drawbacks are of the section, it will be noted that the top of the Eocene shows indeed a proper shelf, practically horizontal and falling off into deeper off-shore areas in the neighbourhood of K-68 and K-85. The difference between the vertical and the horizontal scale perhaps creates a false impression. It is therefore of interest to state that this shelf at the end of the first "cycle" is about horizontal over a width of some 4·5 miles (7 km) and has a sloping approach to shore of some 3 or 4 miles (5–6½ km) giving

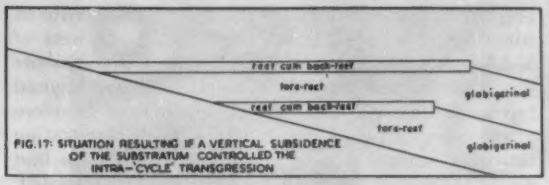


FIG. 17: SITUATION RESULTING IF A VERTICAL SUBSIDENCE OF THE SUBSTRATUM CONTROLLED THE INTRA-'CYCLE' TRANSGRESSION

a total width of some 8 or 9 miles (approx 13 or 14 km —see Fig 16).

Therefore, such a shelf as was postulated on p. 235 did in fact exist, and it may well be that the origin of the reef complex can be deduced from certain characteristics mentioned on the tabulation of p. 238.

It is immediately obvious that the reef did not grow under transgressive conditions, outbalanced by reef growth. Nowhere are there any indications that the reef and back-reef facies of each unit exceeded 50–60 m in thickness.

Nor can regression, with continuing reef growth outbalancing its effects to some extent, have produced the conditions under which the reef " cycles " were formed. The belt of reef and back-reef is far too wide, and there are large areas where the combined thickness of those facies is perfectly constant.

The only remaining possibility, that the reef grew on a stable shelf, therefore needs further investigation.

It is indeed a striking fact, noticeable in Fig 16, that the thickness of the reef and back-reef remains constant over long distances. The lower back-reef and reef nowhere exceeds 100 ft thickness. The upper back-reef is somewhat thicker here and there, but never exceeds about 120 ft.

The same holds true for the thickness of the fore-reef, but this argument is not of great strength, because it is possible on a subsiding horizontal shelf to produce similar constancy.

It is the extraordinary constancy of thickness of the back-reef and reef facies of both " cycles," and the fact that it always measures less than 165–200 ft, which are very strong indications that the reef actually did grow over a stable sub-horizontal shelf.

The conclusion therefore is that during the Oligocene in Kirkuk two successive emigrating reefs existed, growing over a stable shelf, separated from each other by the above-mentioned transgression. There is therefore no indication that any of the " cycles " were built up during a transgression, the transgression is limited to the period in between the two " cycles " (see also Conclusions).

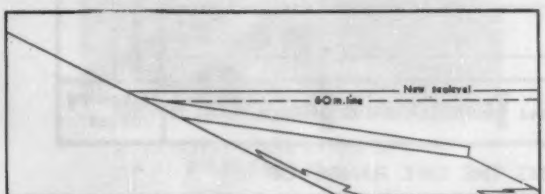


FIG. 18: DIAGRAM SHOWING THE CREATION OF A POTENTIAL REEF ENVIRONMENT CLOSE TO THE SHORE THROUGH TILTING AND SLIGHT SUBSIDENCE.

The question may be asked what sort of movement controlled this transgression. Was it purely a rise of sea-level (or a corresponding vertical subsidence of the substratum) or was it tilt of the substratum ?

There are theoretical indications that vertical movement of the substratum actually can produce the desired effect but tilt seems to fit the facts better.

The top of the first " cycle " will have been approximately horizontal (apart from its off-shore equivalents). If, therefore, rise of sea-level was the actual cause of transgression this top would become covered by a constant depth of sea water after the transgression. If that depth exceeded 50–60 m reef could start growing only on or immediately in front of the new shore line. But it could not grow far without shedding fore-reef debris in front of it, and covering therewith the back-reef deposits of the older " cycle," even in the area close to the shore. Never, it seems, could it manage to grow directly on top of the lower back-reef. Fig 17 illustrates this point diagrammatically.

If, in this case, the rise was less than 50 or 60 m, the reef could start growing at any place, even on the actual back-reef of the lower " cycle." The moment such reef started to grow separation between back-reef and fore-reef would be a fact. Therefore, in this case back-reef could indeed overlie back-reef, as is the fact in Fig 16.

However, it is then necessary that the combined thicknesses of back-reef, reef, and fore-reef should not exceed the 50–60 m thickness. The depth of the sea in front of the original reef must have been of the order of 50–60 m, otherwise the reef could not have started growing.

It is an established fact that the combined thicknesses of back-reef, reef, and fore-reef of the second " cycle " are thinner than the same thickness for the lower " cycle." It is also a fact that in general the combined thickness of the entire upper " cycle " is of the order of 200 ft or less, though some higher values occur in the south-western wells on the Baba dome.

It seems therefore that this thickness is certainly not in excess of what could be expected if sea-level rise was the only agency of transgression. Out of a total number of forty measurable values only three exceeded 200 ft. Values south-east of the area where lower back-reef and reef change into lower fore-reef and off-shore deposits must be excluded.

A definite case can therefore be made for a transgression resulting from rise of sea-level only (or vertical subsidence of the substratum). In order to produce the required configuration the movement should not exceed 165–200 ft.

An equally good case can be made, however, for tilt of the substratum combined with a small rise in sea-level or a vertical subsidence of the substratum. Figs 18 and 19 demonstrate diagrammatically that in such case back-reef can cover back-reef as required. Thickness of the fore-reef is dependent only on the amount of tilt. Such thickness should be small near the original reef, increasing seawards. Those requirements are fulfilled in Kirkuk.

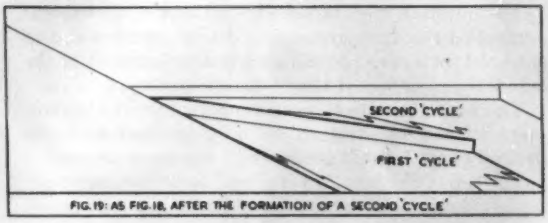


FIG. 19: AS FIG. 18, AFTER THE FORMATION OF A SECOND 'CYCLE'

There is consequently little to choose between these two possibilities. A purely vertical movement, however, would bring the surface of the first reef cycle downwards, keeping its near-horizontality. Fig 16 shows that the top of the first "cycle" is not horizontal, there being a distinct angle between the horizontal and the top of this "cycle."

It would seem therefore that there is at least somewhat more support for the hypothesis that tilt governed the inter-"cycle" transgression. An additional reason to adopt this hypothesis is discussed in the following section.

One interesting observation remains to be noted: all conglomerates between the two "cycles" occur between two back-reefs. Obviously, these conglomerates must therefore have been deposited in the original lagoon of the second "cycle." Their contents cannot have passed before deposition through a reef wall farther coastwards, which would be necessary had they been deposited originally seawards of that reef wall. Moreover, in that case they should be expected to be covered by fore-reef of the upper "cycle." They cannot either have been deposited after the reef had passed their present position on its emigration, because then upper fore-reef should occur below them and probably upper back-reef as well.

The original lagoon must have been localized by an original reef wall south-east of the south-easternmost conglomerates in K-18 and K-86 and north-west of K-14 and K-87, where the upper "cycle" sediments occur in fore-reef facies. The width of the original lagoon of the upper "cycle" must have been therefore of the order of 1½ or 2 miles only. Wells penetrating into this original lagoon cannot be expected to find reef. Only back-reef will be and has been recorded.

THE PALÆONTOLOGY OF THE OLIGOCENE

Until now only the distribution of facies in the Oligocene of Kirkuk has been dealt with. The configuration suggests strongly the existence of two emigrating reef "cycles" separated by a transgression.

Facies planes in emigrating reef facies should cut upwards across time planes in a basinward direction.

As the entire Oligocene is truncated by the Lower Fars (Miocene) transgression, a palæogeological map of the upper "cycle" below the basal Fars conglomerate should show a succession of faunizones from old to young from shore to basin, whereas a similar map on top of the lower "cycle" should show a similar picture.

Moreover, the outermost (youngest) faunizone of the lower "cycle" should be older than the innermost (oldest) faunizone of the upper "cycle," because they are separated by a transgression. This transgression is believed to have been of short duration, *vide* the thinness of the inter-"cycle" conglomerates, so that the difference in age between these faunizones is probably only slight.

The results of the palæontological examination have been condensed mostly in tabular form. Although most wells have actually been examined, it has been considered superfluous to show a range chart for more than one well. K-109 was chosen (Fig 6). The re-

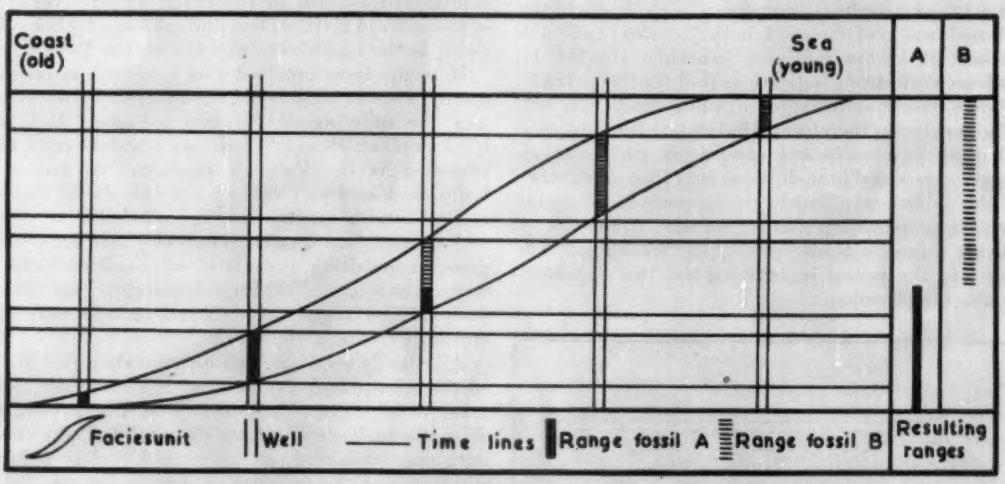
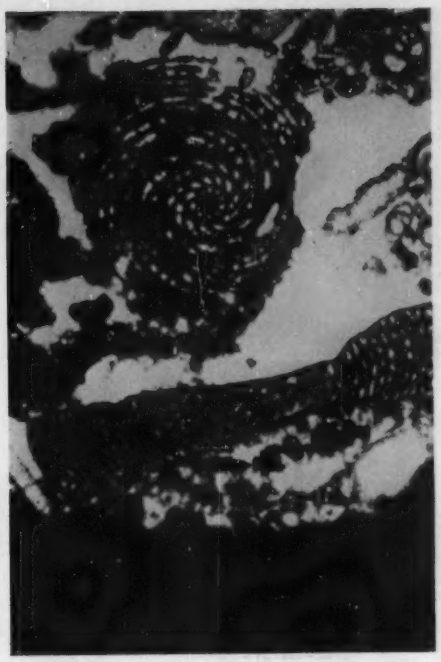


FIG. 20: DIAGRAM EXPLAINING THE LIFE RANGE OF FACIES FOSSILS IN A MIGRATING REEF ENVIRONMENT

A



B

C

D

A—*ARCHAIAS KIRKUKENSIS* HENSON
K-57, 3 ft BLFC, ×30.

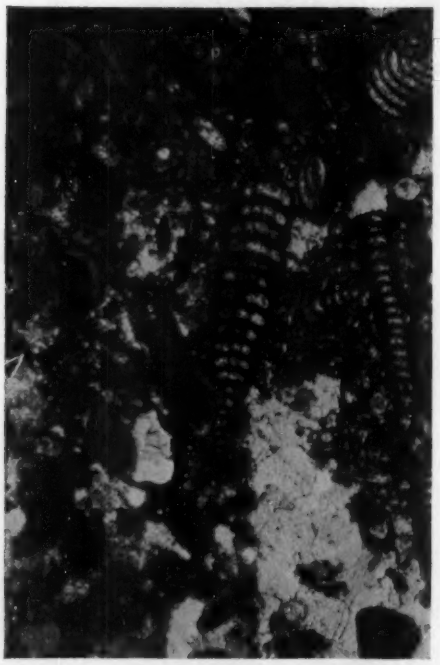
B—*PENEROPLIS EVOLUTUS* HENSON
K-56, 3 ft BLFC, ×38.
Note also *Archaias kirkukensis* Henson.

C—*PENEROPLIS THOMASI* HENSON
K-19, 13 ft BLFC, ×25.

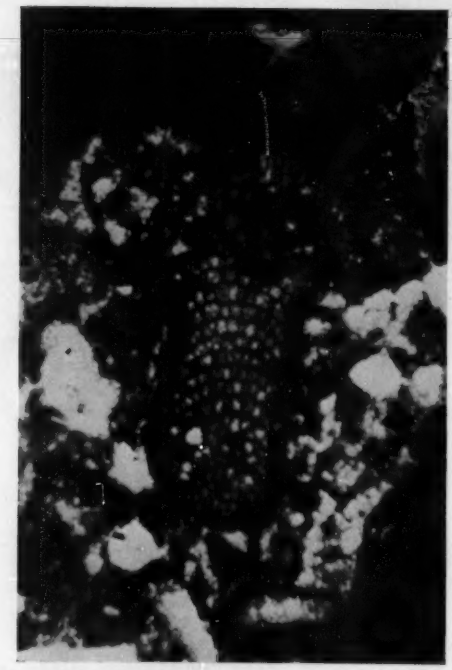
D—*AUSTROTRILLINA HOWCHINI* (SCHL.)
K-19, 13 ft BLFC, ×25.

[*To face p.* 248.

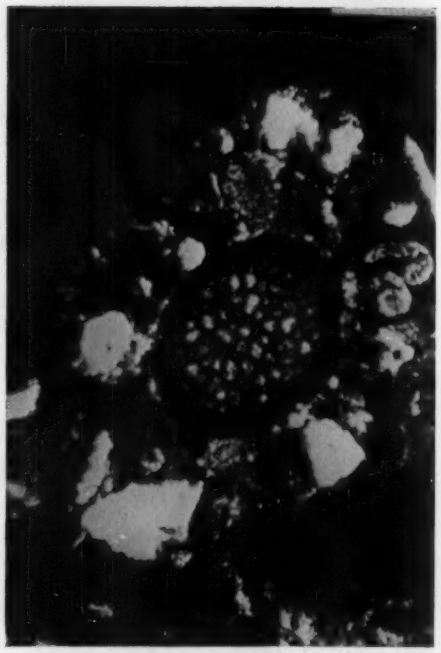
A



B



C



D

A—*PRAERHAPIDIONINA DELICATA* HENSON
K-28, 40 ft BLFC, × 25.

B—*DENDROPHYLLUM cf GURGURDANENSIS* THOMAS (MS)
K-25, 37 ft BLFC, × 40, longitudinal section.

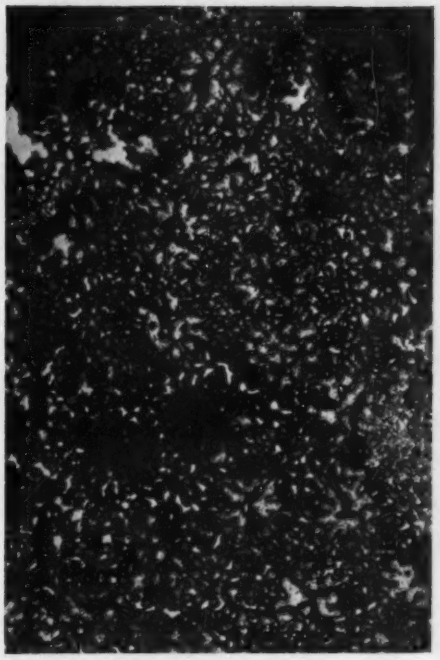
C—*DENDROPHYLLUM cf GURGURDANENSIS* THOMAS (MS)
K-25, 37 ft BLFC, × 40, "vertical" section.

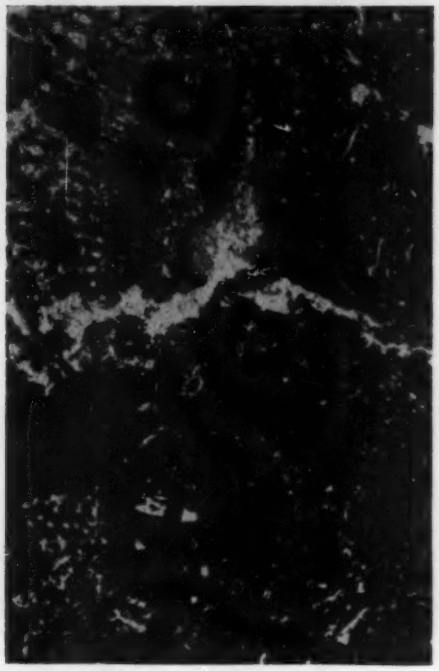
D—*ARCHAIAS OPERCULINIFORMIS* HENSON
K-14, 34 ft BLFC, × 20.

A

B

C





D

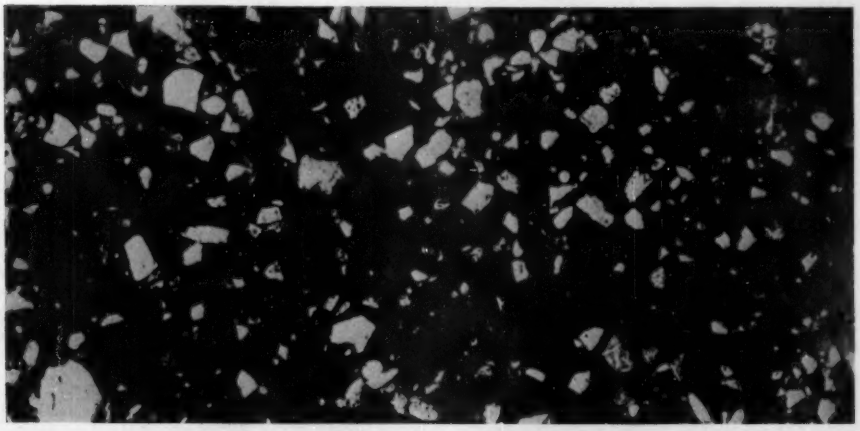
A—*AUSTROTRILLINA PAUCIALVEOLATA* GRIMSDALE
K-14, 34 ft BLFC, 1–5 and 7–9: ×13; 6: ×17.

B—*HETERILLINA HENSONI* GRIMSDALE
K-14, 34 ft BLFC, 1–5: ×13; 6: ×17.

C—OLIGOCENE REEF CORAL, PROBABLY cf *ACTINACIS* SP.
These corals occur frequently in both Lower and Middle Oligocene. Comparison with Plate VIIIB shows that they also occur in the Upper Oligocene. K-19, 117 ft BLFC, ×8·5.

D—MIDDLE EOCENE REEF CORAL
K-101, 96 ft BLFC, ×8·5.

A



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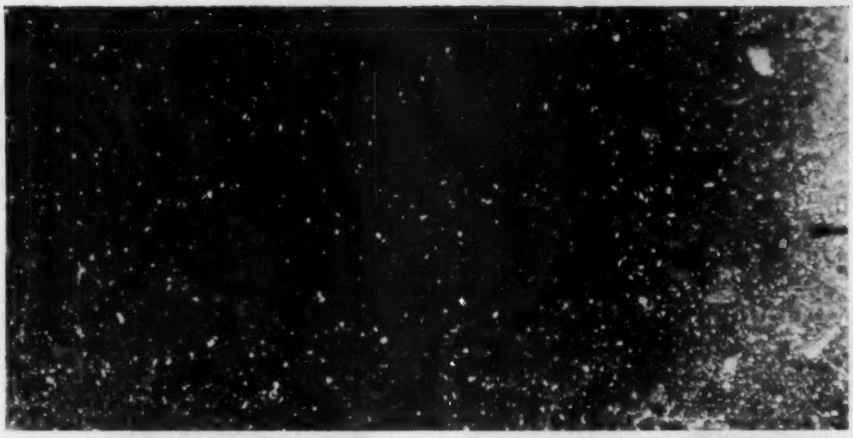
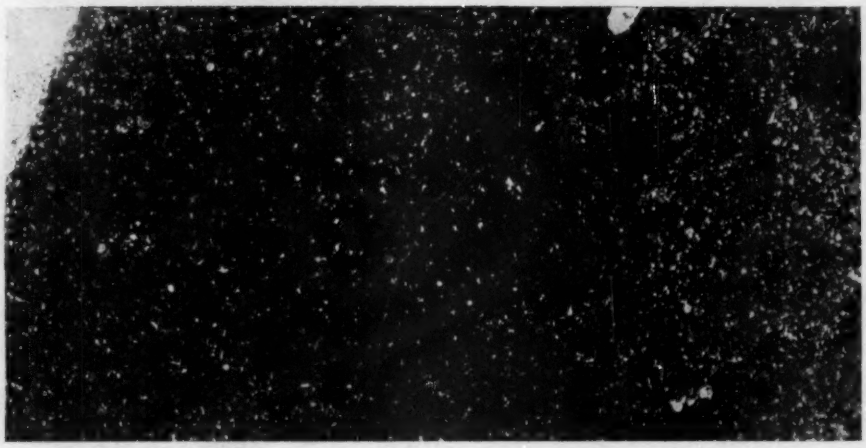


C

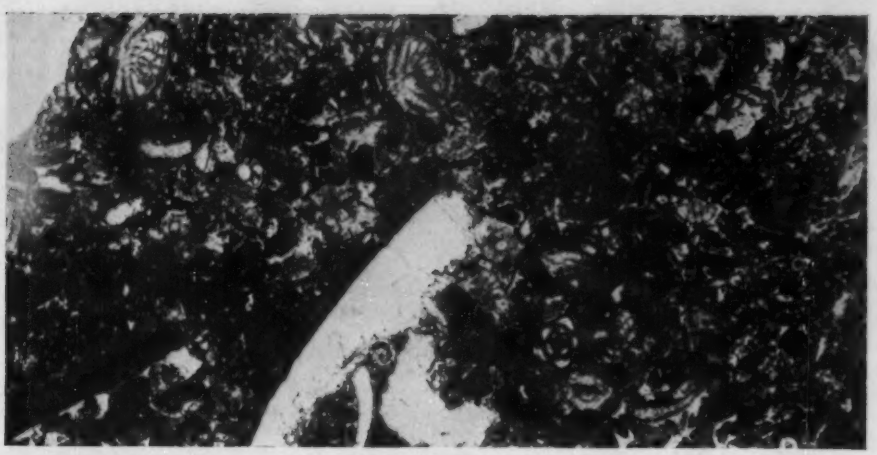


A—LAGOONAL LIMESTONE WITH COARSE GRIT (PYRITE, CHERT, QUARTZ, GREEN ROCK, GLAUCONITE)
Probably Palæocene. K-42, 750 ft BLFC, ×9·5.

B—LAGOONAL LIMESTONE WITH SILT-SIZE CLASTICS, PREDOMINANTLY QUARTZ
Probably Lower Eocene. K-42, 535 ft BLFC, ×9·5.

C—GLOBIGERINAL FACIES, LOWER EOCENE WITH *GLOBOROTALIA ARAGONENSIS*
K-14, 1288 ft BLFC, ×9·5. The Palæocene globigerinal facies differs only in fauna.

A



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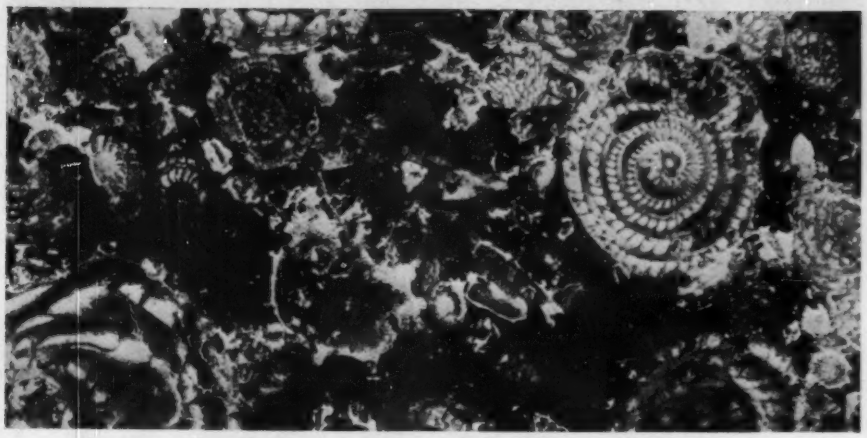
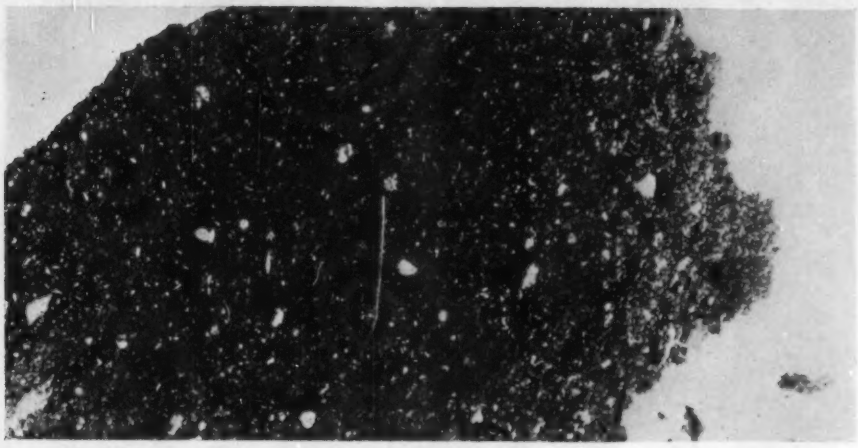


C

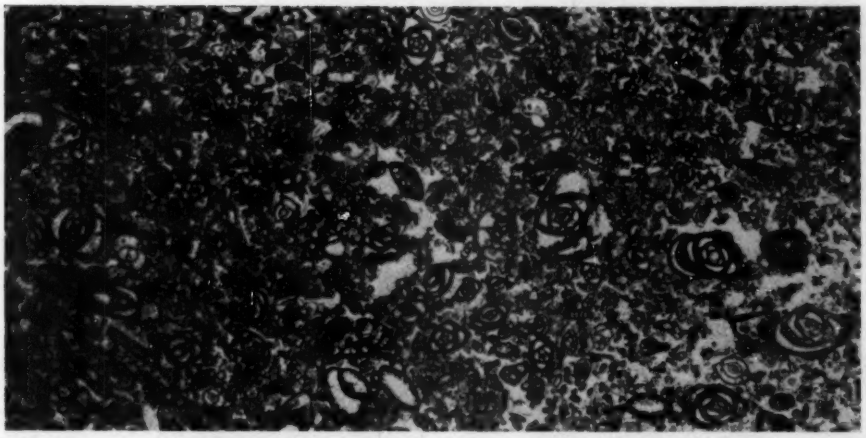


A—LAGOONAL FACIES, MIDDLE EOCENE, WITH *ORBITOLITES COMPLANATUS* AND MILIOLIDS
Nummulitis spp. indicate strong shoal influence. K-40, 25 ft BLFC, ×9·5.

B—SHOAL FACIES, MIDDLE EOCENE, WITH *NUMMULITES* SPP.
K-29, 229 ft BLFC, ×9·5. The Upper Eocene shoal facies is identical apart from the fauna.

C—GLOBIGERINAL FACIES, UPPER EOCENE WITH *GLOBOROTALIA COCOAENSIS* AND *GLOBOROTALIA CENTRALIS*
K-109, 425 ft BLFC, ×9·5. The Middle Eocene globigerinal facies is identical apart from the fauna.

A



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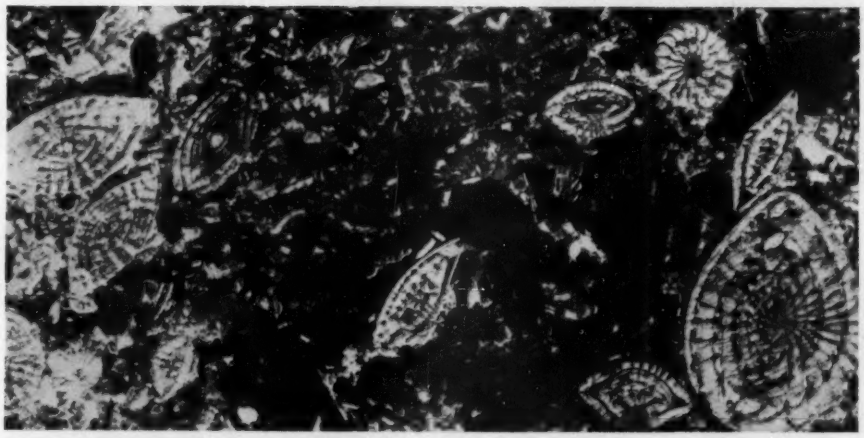
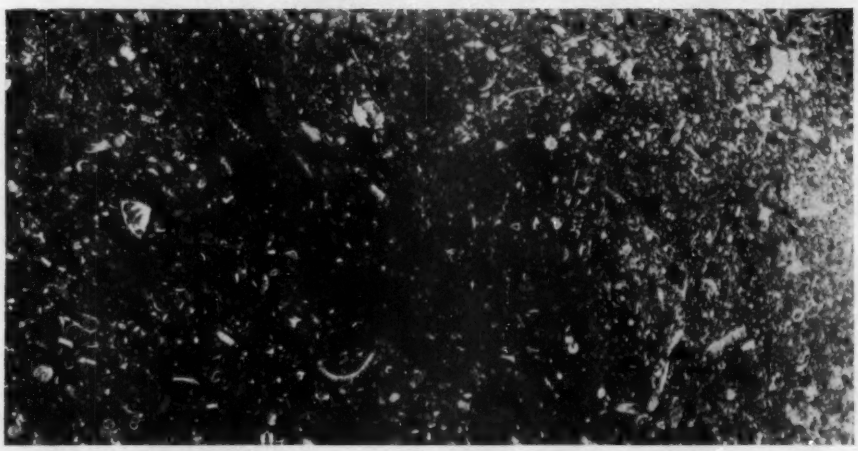


C

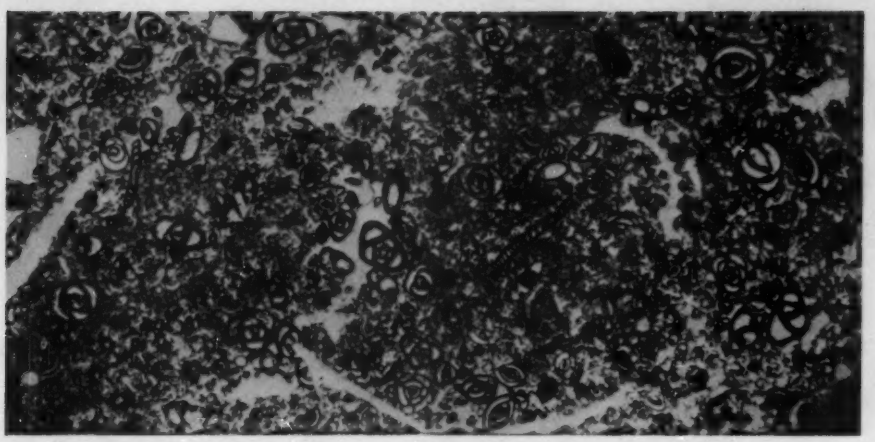


A—BACK-REEF AND FACIES (iii). LOWER OLIGOCENE, *PAUCIALVEOLATA* ZONE
Note also *Heterillina hensoni* and *Austrotrillina paucialveolata*. K-14, 34 ft BLFC, ×9·5. *Shurau formation.*

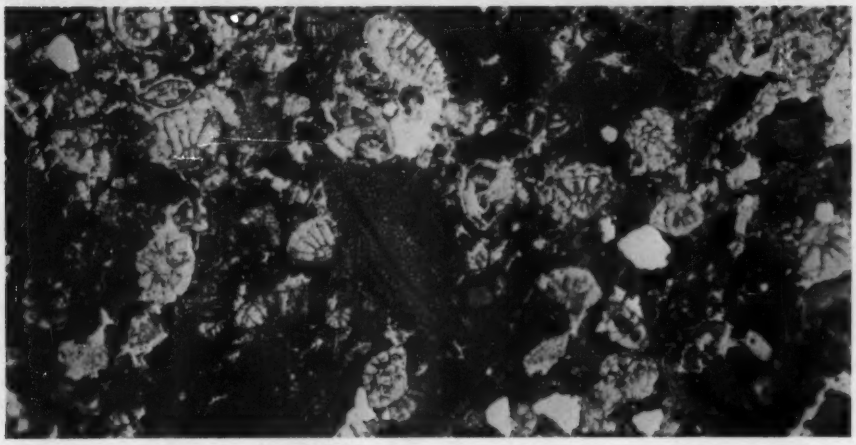
B—FORE-REEF FACIES (ii/i). LOWER OLIGOCENE *NUMMULITES* ZONE
K-14, 131 ft BLFC, ×9·5. *Sheikh Alas formation.*

C—GLOBIGERINAL FACIES (*g*). LOWER OLIGOCENE
K-19, 622 ft BLFC, ×9·5. *Palani formation.*

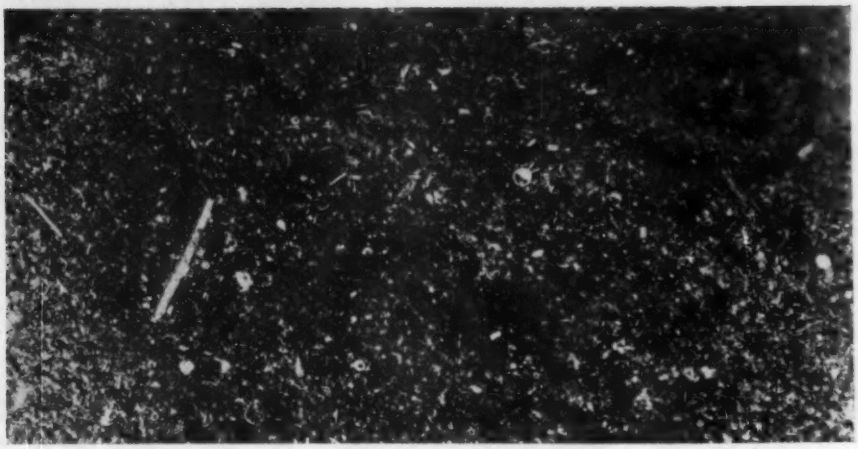
A



B



C

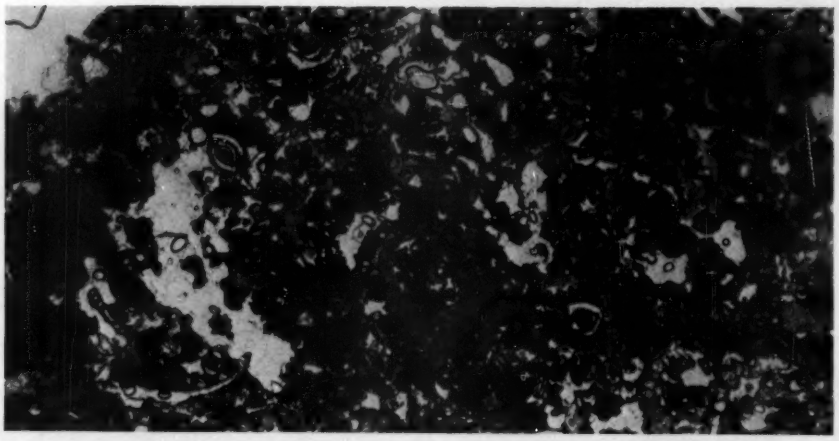


A—BACK-REEF AND REEF FACIES (V), MIDDLE OLIGOCENE, *KIRKUKENSIS* ZONE
K-19, 13 ft BLFC, ×9·5. *Bajawan formation.*

B—FORE-REEF FACIES (IV), MIDDLE OLIGOCENE *LEPIDOCYCLINA* ZONE
K-46, 178 ft BLFC, ×9·5. *Baba formation.*

C—GLOBIGERINAL FACIES (*g2*), MIDDLE OLIGOCENE
K-46, 545 ft BLFC, ×9·5. *Tarjil formation.*

A



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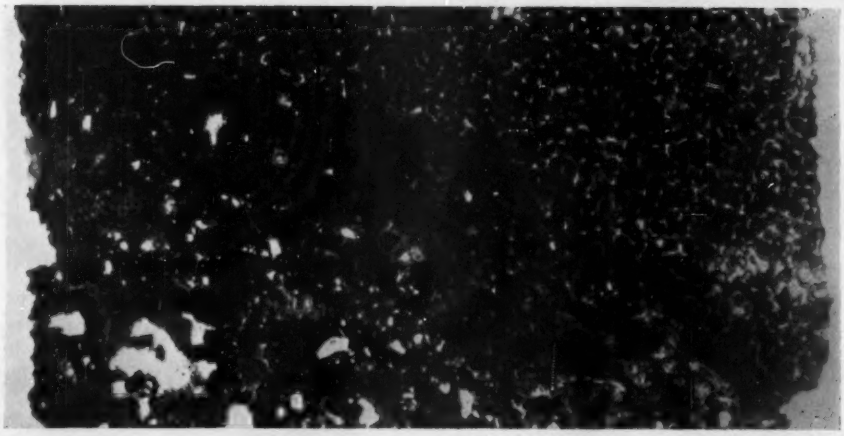
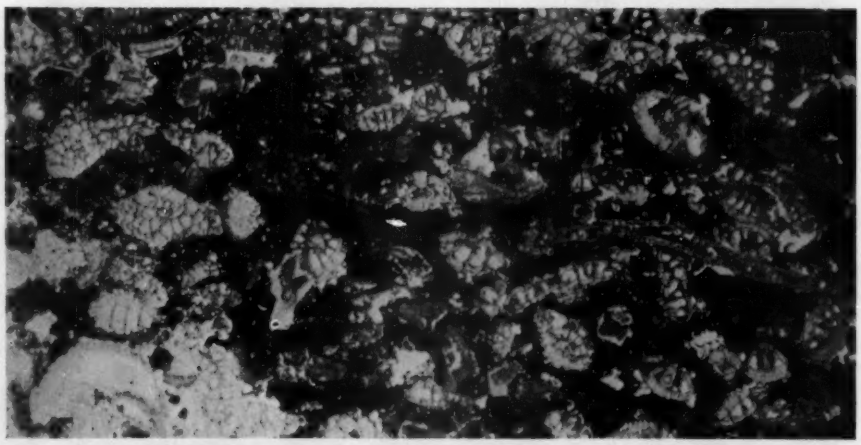


C



A—BACK-REEF FACIES, UPPER OLIGOCENE
Note *Miogypsinoides complanata*. Dara Khurma, ×9·5. *Anah formation.*

B—REEF FACIES, UPPER OLIGOCENE
Note contact reef–fore-reef, the last with *Miogypsinoides complanata*. Ali Rash, ×9·5. *Anah formation.*

C—FORE-REEF FACIES, UPPER OLIGOCENE WITH *MIOGYPSINOIDES COMPLANATA* AND *LEPIDOCYCLINA* SP.
Note also *Rotalia viennoti*, of no particular index value. Azkand, ×9·5. *Azkand formation.*

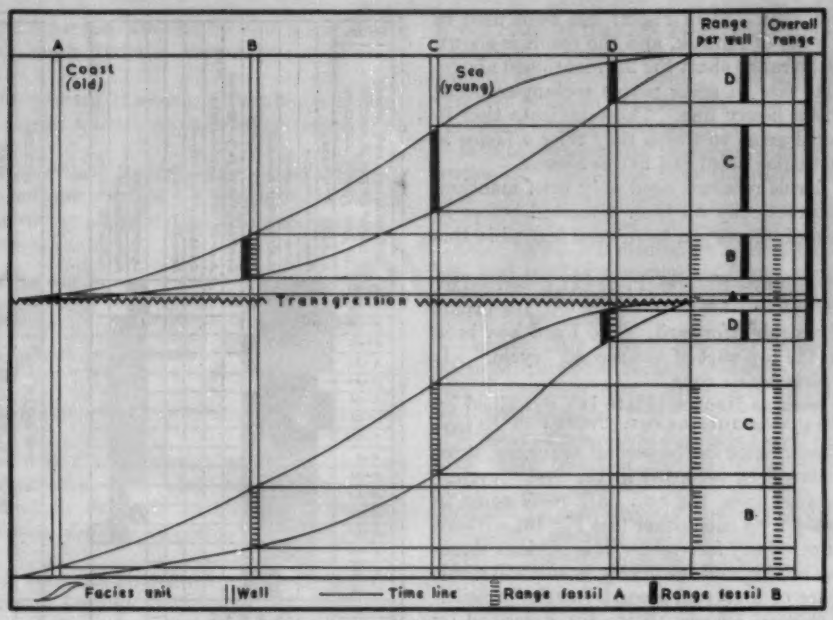


FIG-21 : DIAGRAM EXPLAINING THE LIFE RANGE OF FACIES FOSSILS IN TWO SUCCESSIVE MIGRATING REEF ENVIRONMENTS SEPARATED BY A TRANSGRESSION

maining wells are covered by the composite range chart, Fig 22, which is explained later.

Many more fossils occur than are noted in Fig 6. Mostly, they are indeterminable miliolids, etc. Only those which proved to have index value combined with reasonably frequent occurrence have been included.

It proved impossible to go into such detail as to record first and last occurrence of each fossil in each facies zone. The problem of caving was insoluble here, and the decision was taken to assume that any fossil occurring in one sample of one of the facies in any one well ranges throughout that particular facies in that particular well.

An additional problem was that, though normally a stratum becomes younger vertically, any facies controlled by reefs becomes younger practically horizontally, because of the limitation of vertical growth by optimum depth and sea-level and the consequent mainly horizontal growth.

The range of a fossil in any one place does not therefore necessarily coincide with its total range. This is a well-known principle, but generally the mutually exclusive facies do not alternate as quickly and sharply as they do in thin reef-controlled sedimentation of relatively short duration. Moreover, practically all fossils in the material dealt with are facies fossils, and those which are not are all rather long-living forms.

It is therefore necessary, once the oldest occurrence of a fossil in a reef-controlled facies has been recorded, to find out where the successively younger facies in question occur, in order to determine whether or not the fossil is still present in that facies at a later time. Therefore the direction of facies lines must be known. The direction is assumed to be N-110°-E (and approximately N-120°-E in the Avanah area) with the reservations noted and discussed above. The advantage of knowing the facies line direction is that the position of each well in regard to this direction will give the proper " vertical " succession within that particular facies. Diagrammatically, Fig 20 clarifies this point.

Each facies unit of the Oligocene of Kirkuk has a time range between its earliest and latest occurrences throughout the area which is equal to that covered by the whole reef " cycle " to which it belongs. For instance, the upper back-reef and reef facies range throughout the time taken to deposit the entire upper reef " cycle." So also do the upper fore-reef as well as the off-shore facies.

The matter of fixing the range of a particular fossil is complicated by the fact that there are two reef " cycles " on top of each other. The set of wells needed to fix the fossil range has therefore to be used twice : once for determining the occurrence (or absence) of the fossil in question in the lower " cycle " and once for the determination of its occurrence or absence in the upper " cycle." As there is a considerable difference in age between, for instance the lower back-reef and reef and the upper back-reef and reef in any one well, the matter of diagrammatical representation of the procedure followed to fix the range of each fossil becomes somewhat involved. An attempt has been made in Fig 21.

The method explained in Fig 21 has been used in many of the wells of Kirkuk, and the result is shown on the composite range chart Fig 22, mentioned above. It will be seen that in some places rectangles occur surrounded by a heavy line. These indicate that in the geographical areas to which they refer a facies in which the particular fossil can live is absent.

The index fossils retained need only brief mention, as they have practically all been discussed before in the literature and, moreover, have been figured in this paper.

Archaias kirkukensis Henson (Plate IA), described by Henson.[19, p. 43; pl. 7, Figs 3, 4, and 9; and pl. 8, Figs 1–5] Its occurrence is fairly straightforward. The fossil has been found only in the top part of the second "cycle." It marks the "*kirkukensis* zone."

Peneroplis evolutus Henson (Plate IB), described by Henson.[19, p. 37; pl. 5, Figs 12–14; pl. 6, Fig 1; pl. 10, Fig 2] Apart from regular occurrence in the second sequence, three occurrences have been recorded in the first "cycle." In the north-west area, the two back-reefs come in intimate contact with each other (see Fig 16) without the intercalation of any fore-reef. It is obvious therefore that some mixing and reworking *in situ* will result in co-occurrence of first- and second-"cycle" fossils.

Peneroplis thomasi Henson (Plate IC), described by Henson,[19, p. 36; pl. 5, Figs 7–11] seems to be limited to the upper "cycle."

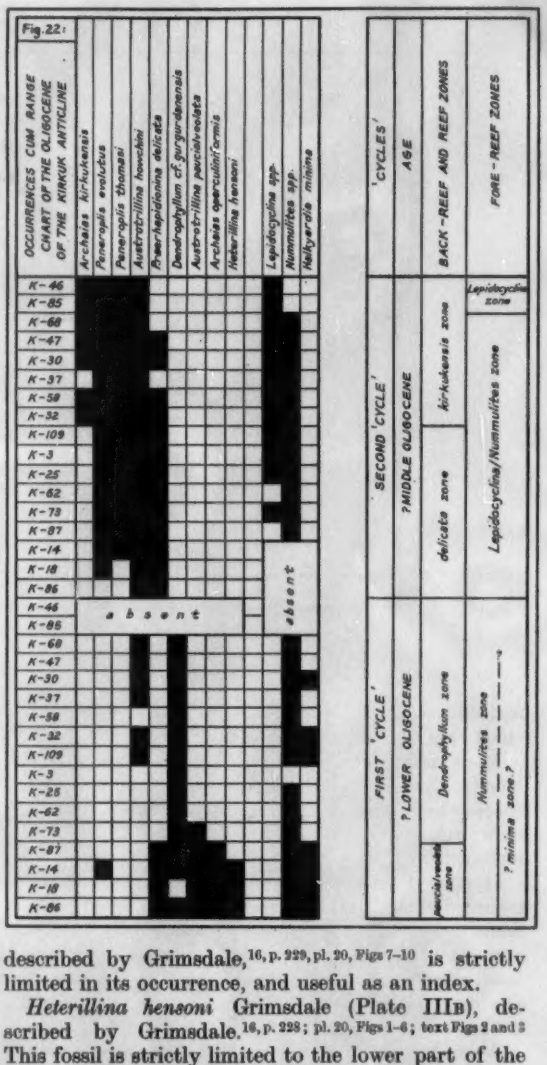
Austrotrillina howchini (Schlumberger) (Plate ID), see also Catalogue of Foraminifera. An easily recognizable fossil which occurs in the higher part of the lower "cycle" and throughout the upper "cycle." The index value is limited therefore, but its frequent occurrence merits it a place amongst the mentioned fossils.

Praerhapidionina delicata Henson (Plate IIA), described by Henson.[19, p. 52; pl. 2, Figs 4, 6, and 9] The few occurrences in the first "cycle" of the northern wells can be explained by mixing and reworking *in situ* between the two back-reefs there. It is used as an index for the *delicata* zone, which is defined below. Grimsdale introduced this zone first in Company records, and the present work is only an elaboration of his, based on more material. Henson records the fossil, probably mistakenly, as Lower Oligocene and questionably Upper Oligocene. It will become apparent below that probably a Middle Oligocene age has to be adopted.

Dendrophyllum cf gurgurdanensis Thomas (MS). The description of this fossil has not yet been published. Some photographs were made available by Dr A. Smout of the Iraq Petroleum Company's Geological Research Centre. The fossil, as it occurs in Kirkuk, resembles these photographs to a great extent—see Plate IIB and C. It is a most useful index fossil for the lower "cycle."

Archaias operculiniformis Henson (Plate IID), described in Henson.[19 *loc. cit.*, p. 44, pl. 7, Figs 5 and 6] Difficult to determine in general because of its resemblance in random sections to *Archaias kirkukensis*.

Austrotrillina paucialveolata Grimsdale (Plate IIIA),



described by Grimsdale,[16, p. 229, pl. 20, Figs 7–10] is strictly limited in its occurrence, and useful as an index.

Heterillina hensoni Grimsdale (Plate IIIB), described by Grimsdale.[16, p. 228; pl. 20, Figs 1–6; text Figs 2 and 3] This fossil is strictly limited to the lower part of the lower back-reef.

The above brief remarks deal with fossils limited to the back-reef and reef facies. The following deal with those fossils which are of importance in the fore-reef facies of both associations.

Lepidocyclina spp. Grimsdale established first that a closer determination into species of this group did not add any refinement to the zonation. The number of *Lepidocyclina* spp. (*sensu lato*) is small and practically restricted to the following: *Lepidocyclina ephippioides* Jones and Chapman, *Lepidocyclina yurnagunensis* Cushman, and *Nephrolepidina marginata* (Michelotti). No photographs of these well-known fossils have been appended.

Nummulites spp. Here again Grimsdale established that further specification would not lead to further detail. Greatly predominant is *Nummulites inter-*

medius-fichteli d'Archiac and Haime but a few simple and indeterminable radiate *Nummulites* spp. occur as well.

Halkyardia minima (Liebus), "Catalogue of Foraminifera," occurs sporadically and is therefore of no great value.

On the basis of these fossils and with the aid of Fig 22, zonation became possible. The result is shown on the composite range chart and may be summarized as follows:

Back-reef and reef	Fore-reef
kirkukensis zone	*Lepidocyclina* zone
delicata zone	*Lepidocyclina–Nummulites* zone
---------- transgression ----------	
Dendrophyllum zone	*Nummulites*
paucialveolata zone	zone (?*minima* zone)

The following remarks serve to elucidate this matter somewhat.

The *kirkukensis* zone coincides with the range of *Archaias kirkukensis* and also carries *Peneroplis evolutus*, *Peneroplis thomasi*, *Austrotrillina howchini*, *Praerhapidionina delicata*, together with numerous miliolids.

The *delicata* zone can be defined, chiefly negatively, on the absence of *Archaias kirkukensis*, differentiating it from the overlying unit and on the absence of *Dendrophyllum cf gurgurdanensis* differentiating it from the underlying unit, the lower back-reef.

The *Dendrophyllum* zone needs no clarification except to point out that in odd occurrences of *Dendrophyllum cf gurgurdanensis* Thomas (MS) together with *Praerhapidionina delicata* Henson the last fossil should be disregarded for the purpose of dating and those occurrences should be considered as belonging to the *Dendrophyllum* zone.

Although the index fossil of this zone ranges downwards, the occurrence of three rather distinctive fossils calls for the introduction of another zone, and this is termed the *paucialveolata* zone.

Zonation in the fore-reef facies is less close, and there is little or no need to discuss it.

It should be noted that in the above tabulation it is not claimed that the *kirkukensis* zone of the upper back-reef is equivalent in age to the *Lepidocyclina* zone of the upper fore-reef. Nor is such relationship claimed between the *delicata* zone and the *Lepidocyclina–Nummulites* zone.

It is of interest and importance to show the distribution of these zones over the field. For that purpose the cross facies section, discussed above, has been completed by adding the fauni-zones (Fig 23).

Once again, the results are to some extent misleading, and further comment is found on p. 245. The actual limits between the various fauni-zones are partly hypothetical.

The resulting picture is self-explanatory and, it is believed, furnishes further proof for the existence of two emigrating reef-controlled "cycles" separated by a transgression.

A point of interest is that it is found that the oldest fossil zone reaches further shorewards than the younger one. In the lower one the *paucialveolata* zone can be seen directly underlying upper "cycle" sediments, whereas the *delicata* zone of the upper "cycle" directly underlies Lower Fars, close to the shore.

This can be the result of two factors, or of a combination of these.

There is tilt to explain emergence of the back-reef close to the shore, subjecting it to erosion which truncated the top part of the lower back-reef, leaving the lower part only, the *paucialveolata* zone. It will be remembered (pp. 247 *et seq.*) that there are additional arguments for tilt during the inter-"cycle" break.

Another possibility is explanation by sedimentary means. In a lagoon, when the sea-level remains constant, continuous shallowing through sedimentation must be expected. The shallowest parts will therefore fill up before the deeper parts. Thus, the shallower parts will contain only older sediments, as against the deeper parts, which will hold sediments of the older as well as of the younger generation. Therefore, under stable conditions, it is possible that the *paucialveolata* zone will reach farther towards

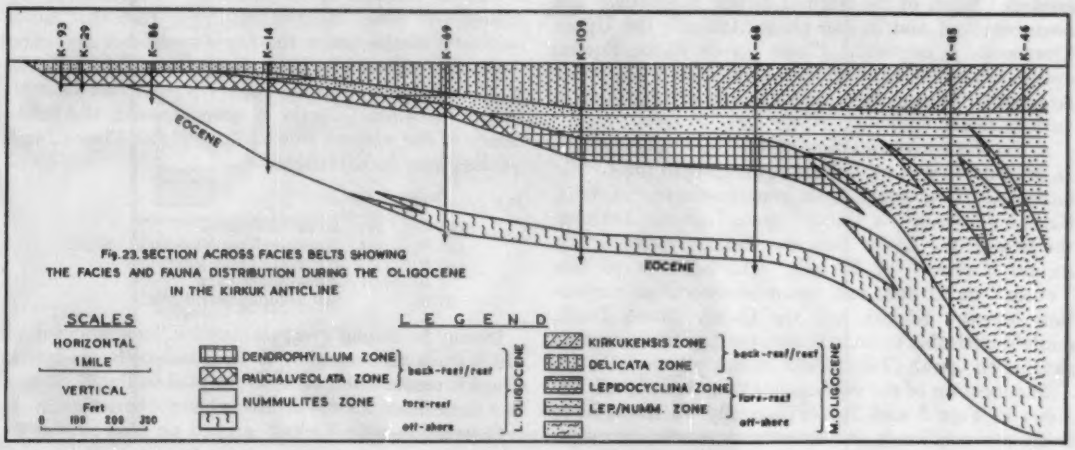


Fig. 23. SECTION ACROSS FACIES BELTS SHOWING THE FACIES AND FAUNA DISTRIBUTION DURING THE OLIGOCENE IN THE KIRKUK ANTICLINE

the land than the elsewhere covering *Dendrophyllum* zone.

It is possible, in principle, to explain the stratigraphy close to the shore by purely sedimentary means. Whether those sedimentary means can explain in full all the findings is doubtful. The width of the *paucialveolata* zone, before it is joined or replaced by the *Dendrophyllum* zone, is of the order of 4 miles. It is not considered likely that this can be explained by purely sedimentary means.

A SECTION ACROSS FACIES LINES THROUGH THE MAIN LIMESTONE OF KIRKUK STRUCTURE

The foregoing remarks complete the discussion of the stratigraphy of the Main Limestone of Kirkuk. Fig 24 has been added to show a complete section through the Kirkuk Main Limestone. It is a combination of the two cross-sections given previously and has consequently the combined disadvantages of both. Moreover, there is little doubt that the facies lines of the Palæocene–Eocene section are not parallel to those of the Oligocene.

This figure was constructed simply, by overlapping the two components in the area of common wells and adjusting small differences in distances between the projected wells.

It is interesting to note that the Upper Eocene is not, as it should normally be, in contact with Lower Oligocene below the Lower Fars. Owing to the inter-"cycle" transgression, the upper "cycle" overlaps over the lower one to a certain extent, and thereby is in somewhat anomalous contact with the Upper Eocene.

THE STRATIGRAPHY AND PALÆONTOLOGY OF THE OLIGOCENE OF THE QARAH CHAUQ DAGH

The Qarah Chauq Dagh is a structure similar to the Kirkuk structure, though very much more deeply eroded. Much of its original Lower Fars cover has been removed and in one place (Azkand) the Upper Cretaceous is exposed. Three places where Eocene occurs at surface have already been dealt with, and a large part of the mountain is made up of Oligocene in various facies.

A detailed investigation of material collected by D. M. Morton and F. J. Venn, geologists of the I.P.C., indicated that, apart from representatives of both Kirkuk "cycles" a third "cycle" occurs between the base of the Lower Fars and the equivalent of the second "cycle" of Kirkuk. The absence of this "cycle" in Kirkuk, and the otherwise close correlation between Kirkuk and the Qarah Chauq Dagh, made it desirable to include the result of these investigations on Qarah Chauq Dagh in this paper.

The location of the surface sections, eight in all, are given in Figs 2 and 33. Practically all material is badly recrystallized, and sometimes conclusions were reached only on the basis of knowledge gained from the Kirkuk structure.

The northern dome is described first. Fig 27 gives the stratigraphy of the sections involved, and Figs 25 and 26 provide their basis. It can be summarized as follows:

Sheikh Alas:

48 ft	(v)	*delicata* zone
82 ft	(iv)	*Lepidocyclina–Nummulites* zone
65 ft	(iii)	*Dendrophyllum* zone
73 ft	(ii/i)	*Nummulites* zone

An attempt to correlate this succession with what was found in the Kirkuk anticline must consider the following restrictions: the vertical succession in Sheikh Alas of the lower "cycle" shows that this part has to be correlated with the area between K-68 and K-69, limited on both sides by the facies directions of approximately N-120°-E. This can be deduced from Fig 23, where K-69 shows *paucialveolata* zone on *Nummulites* zone and K-68 with the last *Dendrophyllum* zone on *Nummulites* zone. A similar argument for the higher "cycle" suggests that the area of correlation should be limited on the south by a line at N-120°-E through K-109, which shows the last vestiges of the *delicata* zone (see Figs 6 and 22) and to the north by the coast. It is evident therefore that actual correlation should exist with the region where both areas overlap: between a limit running N-120°-E through K-69 and a limit in similar direction through K-109. It is of some interest to note that the thicknesses of the zones of the Qarah Chauq Dagh differ much from their equivalents in Kirkuk. An attempt to explain this is made below.

Malik Agha:

38 ft	(v)	*kirkukensis* zone
147 ft	(iv)	*Lepidocyclina–Nummulites* zone
59 ft unbottomed	(iii)	lower back-reef, unknown zone

No index fossil occurs in the lower back-reef, so that the zone represented cannot be determined. The vertical succession in the upper "cycle" suggests correlation with the area south of a line running N-120°-E through K-32 (the first occurrence of the *kirkukensis* zone, see Fig 22). The fact that lower back-reef occurs below the *Lepidocyclina–Nummulites* limits the region of correlation to the strip between K-32 and K-68 (Fig 23), which should run in a N-120°-E direction. Again, it may be noted, the thicknesses of the various zones in the Qarah Chauq Dagh are less than in Kirkuk.

Pir Daud (2)*:*

63 ft	(v)	*kirkukensis* zone
137 ft	(iv)	*Lepidocyclina–Nummulites* zone
110 ft	(iii)	Indeterminable interval
54 ft	(ii/i)	*Nummulites* zone
57 ft		Indeterminable interval

Owing to strong recrystallization, one interval of 110 ft thick and one of 57 ft thick cannot be classified. Graphic reconstruction, as attempted in Fig 27, shows how these intervals will probably have to be determined.

Correlation with Kirkuk, argued on lines similar to

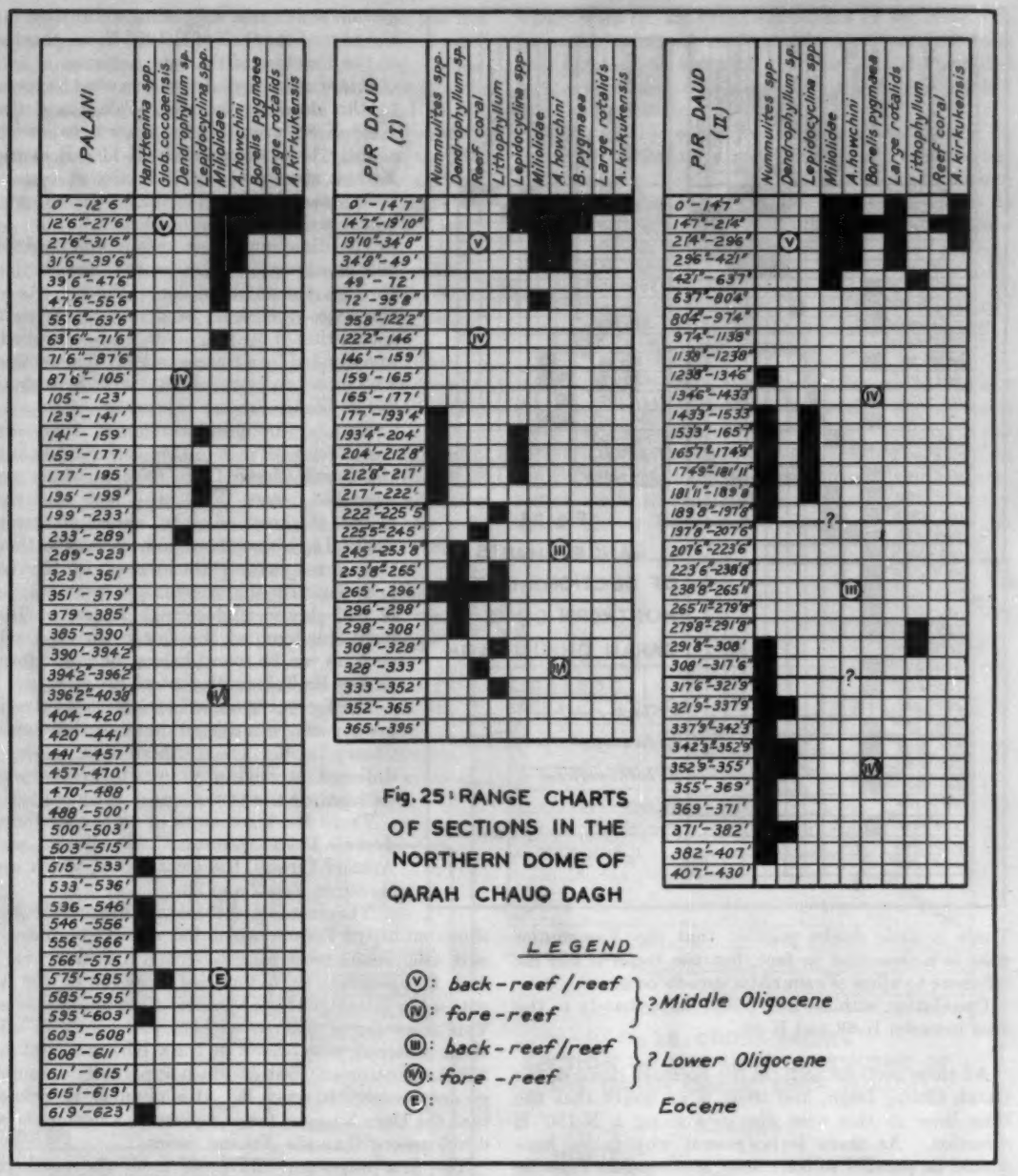


Fig. 25: RANGE CHARTS OF SECTIONS IN THE NORTHERN DOME OF QARAH CHAUQ DAGH

LEGEND

(V): back-reef/reef
(IV): fore-reef
} ? Middle Oligocene

(III): back-reef/reef
(VI): fore-reef
} ? Lower Oligocene

(E): Eocene

the ones used above, should exist with the region between K-68 and K-32, a strip orientated in a N-120°-E direction. Again, it may be noted, thicknesses are less than in Kirkuk.

Pir Daud (1):

49 ft	(v)	*kirkukensis* zone
175 ft	(iv)	*Lepidocyclina–Nummulites* zone
54 ft	(iii)	*Dendrophyllum* zone
100 ft unbottomed	(ii/i)	*Nummulites* zone

Correlation, argued as above, points clearly to the same strip with which Pir Daud (2) could be correlated.

Palani:

35·6 ft	(v)	*kirkukensis* zone
194 ft	(iv)	*Lepidocyclina* zone
282·7 ft	(ii/i)	off-shore fore-reef, zone unknown

The dating of the lower off-shore fore-reef is based on the occurrence of *Dendrophyllum cf gurgurdanensis*.

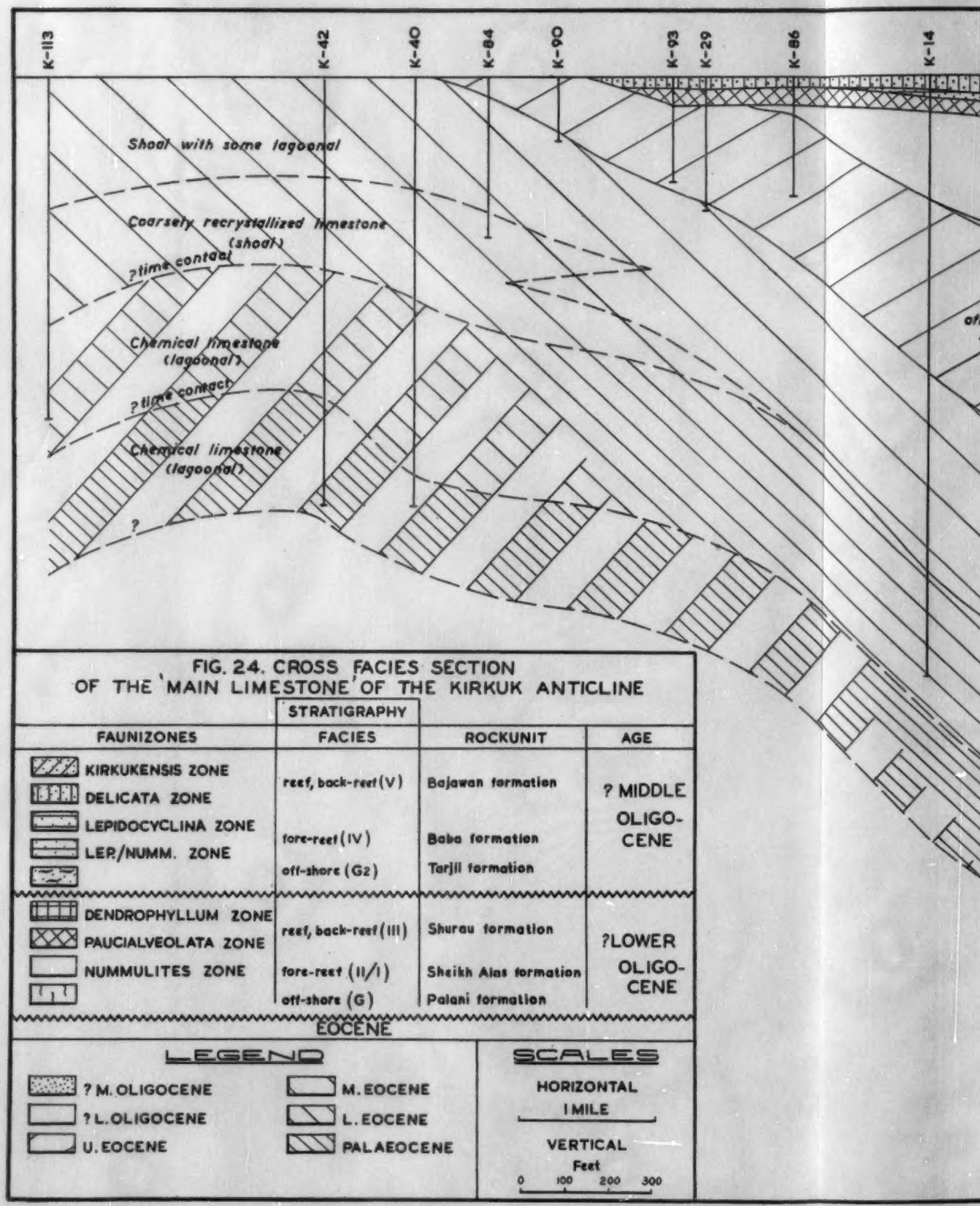


FIG. 24. CROSS FACIES SECTION OF THE 'MAIN LIMESTONE' OF THE KIRKUK ANTICLINE

FAUNIZONES	STRATIGRAPHY FACIES	ROCKUNIT	AGE
KIRKUKENSIS ZONE DELICATA ZONE LEPIDOCYCLINA ZONE LEP./NUMM. ZONE	reef, back-reef (V) fore-reef (IV) off-shore (G2)	Bajawan formation Baba formation Tarjil formation	? MIDDLE OLIGOCENE
DENDROPHYLLUM ZONE PAUCIALVEOLATA ZONE NUMMULITES ZONE	reef, back-reef (III) fore-reef (II/I) off-shore (G)	Shurau formation Sheikh Alas formation Palani formation	?LOWER OLIGOCENE
EOCENE			

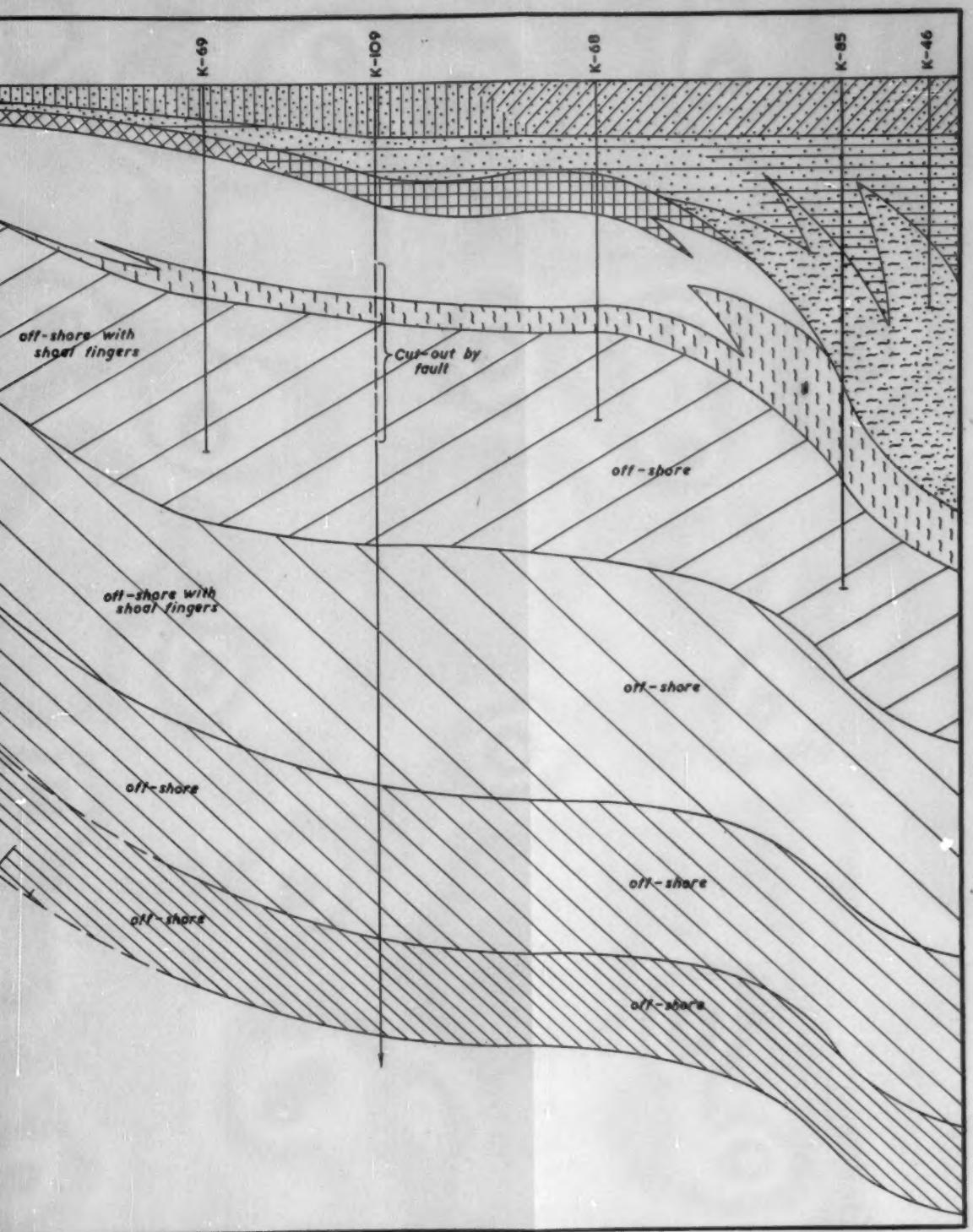
LEGEND

? M. OLIGOCENE
? L. OLIGOCENE
U. EOCENE
M. EOCENE
L. EOCENE
PALAEOCENE

SCALES

HORIZONTAL
1 MILE

VERTICAL
Feet
0 100 200 300


K-69
K-109
K-68
K-85
K-46
off-shore with shoal fingers
Cut-out by fault
off-shore
off-shore with shoal fingers
off-shore
off-shore
off-shore
off-shore

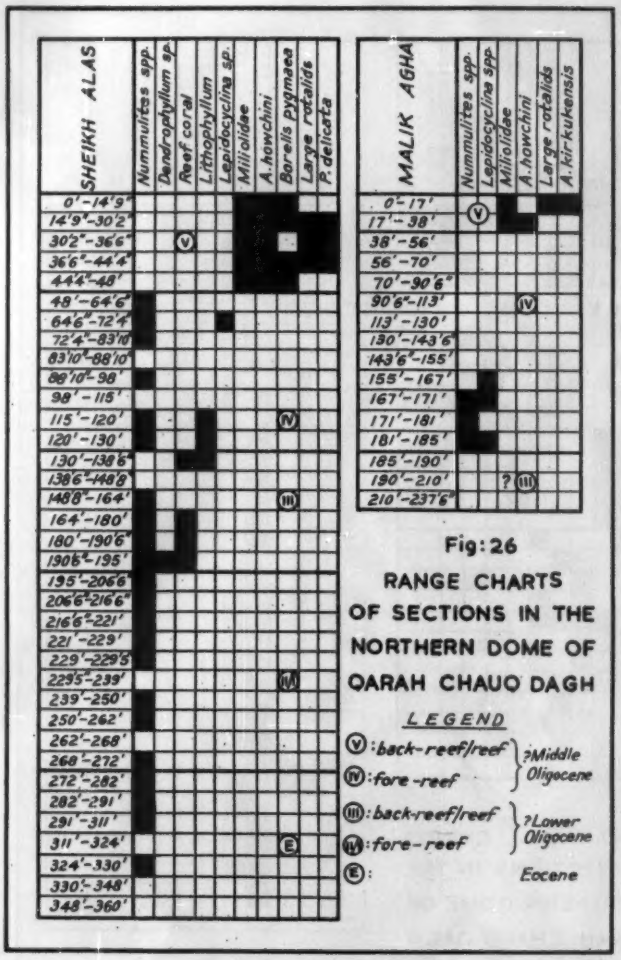


Fig: 26

RANGE CHARTS OF SECTIONS IN THE NORTHERN DOME OF QARAH CHAUQ DAGH

There is little doubt possible that the *Nummulites* zone is represented in fact, but the facies is too far off-shore to allow *Nummulites* spp. to occur.

Correlation with Kirkuk points immediately to the area between K-68 and K-85.

All these sections occur in the northern dome of the Qarah Chauq Dagh, and there is no doubt that the time lines in this area also run along a N-120°-E direction. As there is no reason why facies lines should be parallel to time lines, some means must be found to trace the facies lines as well. This cannot be done in the northern dome alone, as the sections are too few and far between. A facies direction can, however, be estimated once the direction of the actual edge of the reef potential area is known. This edge obviously controls the distribution of the reef, and thereby of the fore- and back-reef facies.

That direction is known to a certain extent, for in the Palani section and in the K-68–K-85 area the lower "cycle" changes its facies to off-shore globigerinal sediments, suggesting a direction for the edge of the shelf of N-120°-E, *i.e.* parallel to the direction of the time horizons.

It is of no immediate concern what happens to this direction between Palani and the K-68–K-85 area. It is known to swing slightly to approximately N-110°-E in the Kirkuk structure, but it is almost certain to approach N-120°-E in the northern dome, which is the area of interest.

This direction has therefore been used for the construction of a cross-facies section through the northern dome, Fig 27. As in the case of Kirkuk, this section shows a bipartition of the Oligocene, reef-controlled, and divided by a transgression. The section also shows strict correlation with Kirkuk as far as faunizones are concerned.

Despite this close correlation, there are two differences in detail between Kirkuk and the Qarah Chauq Dagh (North) which are described later. First, the fact that the overall thickness of each "cycle" in Qarah Chauq Dagh's northern dome is smaller than the corresponding thicknesses in Kirkuk and, secondly, that there is no representative of the lower globigerinal facies in the northern dome of the Qarah Chauq Dagh such as can be found below the lower fore-reef of Kirkuk south-east of K-14.

The foregoing remarks relate to the stratigraphy of the northern dome of the Qarah Chauq Dagh. The southern dome shows a different stratigraphy, which necessitates its separate treatment.

There are three sections on the southern dome, Dara Khurma, Ali Rash, and Azkand Cirque, the locations of which are shown in Figs 2 and 33.

The most complete section, Azkand Cirque, shows on top of Eocene, which has already been dealt with, Oligocene representing the second Kirkuk "cycle" with *Lepidocyclina* sp. in fore-reef facies (33 m, 108 ft) with a few interdigitations of more off-shore sediments. This same facies, though without indications of off-shore material, also occurs in Dara Khurma (102 m, 335 ft unbottomed), but Ali Rash apparently does not go deep enough to reach it. It is obvious, therefore, that the Dara Khurma facies represents a nearer-shore development than the Azkand facies.

The first important difference from the northern dome is therefore the absence of material from the lower "cycle." The contact with the Eocene is glauconitic in Azkand, and absence of the lower "cycle" here is explained by non-deposition or a combination of deposition and submarine erosion and winnowing, which accounts for the glauconite concentration.

It is realized that other explanations can be found. A tectonic explanation, rise at the end of the Eocene, non-deposition of the first "cycle," and resubmergence

during the inter-" cycle " transgression, has the disadvantage of restricting a tectonic event to a small area, as nowhere else in the neighbourhood do indications exist of such movements. Another similar explanation requires emergence at the end of the Eocene and during the lower " cycle," and submergence during the transgression. This has the disadvantage that one would expect the gap between upper " cycle " and Eocene to widen towards the northern dome, whereas in fact material of the lower " cycle " is found there.

Though no direct proof exists, it would seem therefore that the explanation of the absence of the lower " cycle " in the Azkand section through non-deposition and winnowing is the most likely.

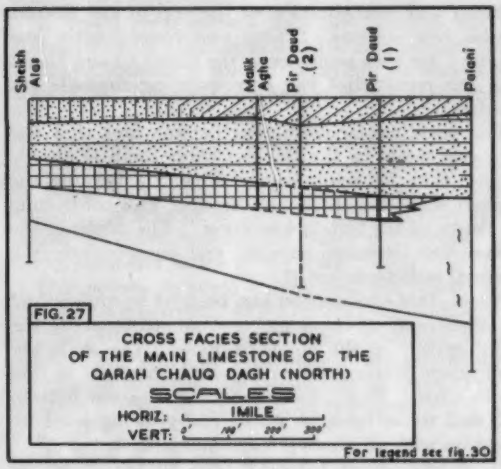
A second important difference from the northern dome is the fact that this second " cycle " material is covered by sediments of yet another reef-controlled " cycle." This is represented as back-reef in Dara Khurma, back-reef and reef in Ali Rash, and back-reef, reef, and fore-reef in Azkand. Figs 28 and 29 elucidate this succession, which is clearly indicative of reef control. This third " cycle " can be subdivided into two faunizones, the first, the lower one embracing fore-reef only and characterized by *Lepidocyclina* spp. and *Miogypsinoides complanata* (Schlumberger), the second, covering this, showing fore-reef and back-reef characterized by *Miogypsinoides complanata* only.*

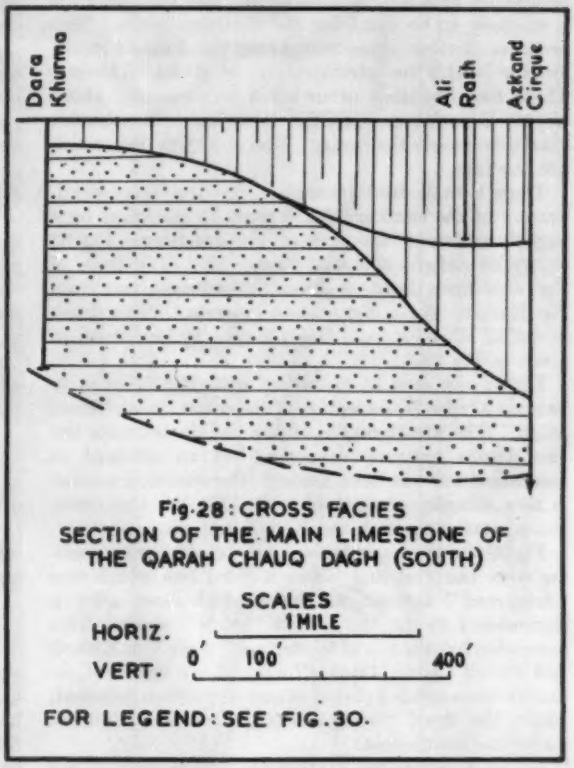
Although too few data are available and although only the coastal part of this third "cycle" is known, it is nevertheless of interest to find out the mode of origin of this "cycle." The back-reef facies increases its thickness rapidly seawards to a measurable maximum of 192 ft, just short of the critical 200 ft. It would seem (p. 235) that subsidence of sea-level outbalanced by strong reef growth could produce such configuration, a regression therefore already heralded by the regression which separates this third " cycle " from its predecessor.

This probable origin has an important bearing on the width of this third reef belt. It will be considerably narrower than the ones known from the Kirkuk " cycles." How narrow cannot be said as yet, as no off-shore sediments of this " cycle " have been found.

CORRELATION BETWEEN THE NORTHERN AND THE SOUTHERN DOMES OF THE QARAH CHAUQ DAGH

There is therefore a good deal of difference between the stratigraphy of the northern and of the southern dome. The absence of the third " cycle " in the northern dome and the absence of the first " cycle " in the southern dome are the most important differences. Variations in thickness of corresponding units in the Qarah Chauq Dagh and Kirkuk anticlines can be




Dara Khurma
Ali Rash
Azkand Cirque
Fig. 28: CROSS FACIES SECTION OF THE MAIN LIMESTONE OF THE QARAH CHAUQ DAGH (SOUTH)
SCALES
HORIZ. 1 MILE
VERT. 0' 100' 400'
FOR LEGEND: SEE FIG. 30.

* The choice of *Miogypsinoides complanata* as an index-fossil for a back-reef environment was necessary because of lack of any other suitable genuine back-reef fossil. It would seem probable that these fossils were swept into the lagoon from the fore-reef realm. If it were possible to demonstrate that *Lepidocyclina* spp. could not have been swept into the lagoon for some reason or other, perhaps because they were too heavy, although they were present in the fore-reef, it would necessitate revision of the concept of two fauni-zones in this " cycle," because absence of *Lepidocyclina* spp. in the back-reef at Dara Khurma would then not have any stratigraphical significance.

Fig. 29: Tabulation for correlations in the Qarah Chauq Dagh (South)

AGE	DARA KHURMA	ALI RASH	AZKAND CIRQUE
? UPPER OLIGOCENE	back-reef 49′ (with Miogypsinoides sp.)	back-reef/reef 140′ (with Miogypsinoides sp.) reef unbottomed 55′ (with Miogypsinoides sp. and Lepidocyclina sp.)	back-reef/reef 195′ (with Miogypsinoides sp.) fore-reef 240′ (with Miogypsinoides sp. and Lepidocyclina sp.)
?MIDDLE OLIGOCENE	fore-reef unbottomed 334′ (with Lepidocyclina sp.)	NOT EXPOSED	fore-reef 108′ with Lepidocyclina sp.
EOCENE	NOT EXPOSED	NOT EXPOSED	off-shore 165′

found by comparing Figs 24 and 28, reproduced in Fig 33.

Neither the time-stratigraphies nor the facies-stratigraphies can be correlated directly. The northern cross-facies section runs approximately perpendicular to a N-120°-E direction, and this direction is unlikely to be valid for the southern dome. This becomes obvious when comparing the Azkand stratigraphy with the stratigraphy of Dara Khurma. These two locations occur on a line running about N-120°-E and, consequently, their facies distribution should be nearly the same. This is, as can be noticed, not the fact.

There is little doubt therefore that the facies stratigraphy of the southern dome must be governed by a slightly different direction of the coastline. Fig 33 shows how slight this swing need be. (The trace of the facies lines there has taken into account data from Bai Hassan, which is discussed later on.) This facies direction allows a cross-facies section to be drawn, as given in Fig 28.

Fig 28 can now be linked up with Fig 27 so as to provide a cross-facies section of the entire Qarah Chauq Dagh. The stratigraphy of the saddle between the two domes remains unknown, but an attempt at reconstruction has been made. The resulting section is now directly comparable with Fig 24, the cross-facies section through the Kirkuk anticline.

Fig 30 shows clearly the second "cycle" transgressing over the first and below a third one which was "triggered" farther off the original shore after a regression had cut the second "cycle" short. This regression left the top of the second "cycle" in Kirkuk and Qarah Chauq Dagh (North) above sea-level, so that in these areas a period of non-deposition followed, whilst the third "cycle" was deposited farther towards the south-west.

All that is known of this third "cycle" is the approximate position of its coastline. In the Qarah Chauq Dagh, this coastline must occur landwards of the seaward edge of the reef-potential area of the second "cycle." Because of absence of material of this third "cycle" in the Tarjil area of Kirkuk, it is obvious that it must pass to the seaward of the edge of the reef-potential area at the end of the Kirkuk structure. Somewhere, therefore, the two lines should cross. Apart from the fact that this crossing must happen between Bai Hassan and Tarjil (see below), nothing further is known about the point of crossing.

Comparing the two cross-facies sections (Figs 24, 30, and 33), differences as already mentioned above between the two stratigraphies can be noticed. Each reef "cycle" in the Qarah Chauq Dagh is thinner than its equivalent in Kirkuk, with the obvious exception of the third "cycle," which is absent in Kirkuk.

The explanation of this phenomenon lies probably in the fact that the original Eocene shelf was shallower, gentler, and broader in the Qarah Chauq Dagh region than in the Kirkuk area. This can be seen from the position and configuration of the top of the Eocene in the two sections. There was consequently less "room" for each sequence in the Qarah Chauq Dagh, with the result that the corresponding deposits are thinner.

The same explanation goes for the fact that the back-reef facies in the Qarah Chauq Dagh is always thinner than its equivalent in Kirkuk. Because the original shelf was shallower, the reef wall controlling the depth of the lagoon was lower. The depth of the lagoon was therefore smaller, and consequently the lagoonal sediments are thinner.

Again, this explanation can be used to understand the absence of off-shore globigerinal sediments of the first "cycle" in the northern dome. The shallower shelf made immediate reef growth possible in the Qarah Chauq Dagh, but in Kirkuk the sea bottom had still to be brought up to reef-growing level by filling up with off-shore globigerinal sediments.

THE PRE-MIOCENE STRATIGRAPHY OF BAI HASSAN No. 3

The structure on which well Bai Hassan No. 3 is located runs approximately half-way between the

Qarah Chauq Dagh and Kirkuk structures. It differs from the Qarah Chauq Dagh in the fact that it is lower and exposes only Lower Fars in the crestal areas, Upper Fars forming the flanks.

BH-3 penetrates the entire Main Limestone and was completed in the top of the Eocene.

This well shows a stratigraphy of the Main Limestone which is of great interest for the entire theory exposed here. The following was found, corrected for dip (Fig 31):

156 ft	*kirkukensis* zone	(v)
232 ft	*Lepidocyclina* zone	(iv)
85 ft	*Lepidocyclina–Nummulites* zone	(iii)
25 ft	*Nummulites* zone	(ii/i)
220 ft	off-shore deposits	(*g*)

Whereas the wells in the Kirkuk structure hardly ever showed a proper coral reef and whereas, in fact, only fragments of reef-forming organisms were found, the reef and back-reef facies here shows a great thickness (145 ft) of actual coral reef. The reason for this is obvious. Whilst the reef moves seawards reef material behind it loses its cohesion and slowly crumbles to fragments, which are subsequently taken up in the back-reef deposits. There is only one situation therefore where actual reef in the form of a surviving reef " wall " can be found. That is where the reef ceases to move in order to build up first a foundation shallow enough to enable reef organisms to grow. A prominent reef " wall " will then develop and be preserved. Migration can take place only after the supply of detritus has raised the sea bottom to reef building level. Migration will generally be arrested at the seaward edge of the shelf, where the latter plunges into depth.

This area in the Kirkuk structure must occur beyond K-46, where lack of points of observation prohibits testing this hypothesis.

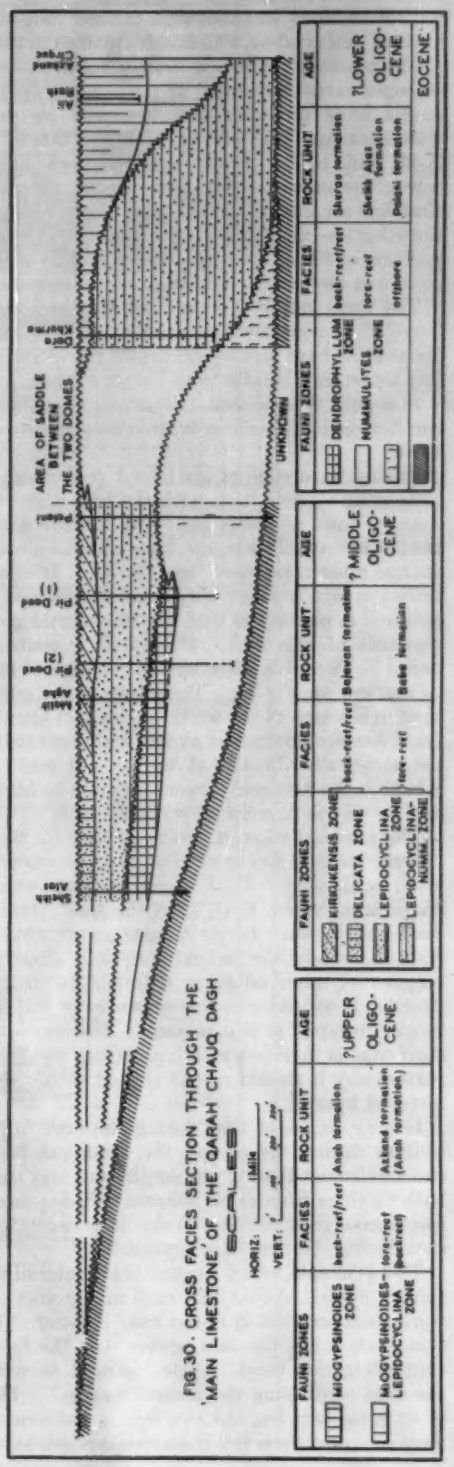
It would seem correct that this point in the Bai Hassan structure coincides with the area around BH-3. If the hypothesis is correct therefore, no wells southwest of BH-3 should show any back-reef of the second " cycle," and this " cycle " should be represented by fore-reef and perhaps off-shore sediments only. One such well has been drilled, about 2 miles south-west of BH-3, and indeed it was found that the second " cycle " is present in fore-reef and off-shore facies, above off-shore material of the first " cycle " and below back-reef facies of the third " cycle."

This proves to some extent that the above given hypothesis is correct. It is here that the main interest of the BH-3 stratigraphy lies. Findings in Bai Hassan also serve to demonstrate the possibility of correlation between the Qarah Chauq Dagh (Palani) and the Kirkuk structure (K-85) as given in Fig 32.

CORRELATION BETWEEN THE KIRKUK, BAI HASSAN, AND QARAH CHAUQ DAGH STRUCTURES

Fig 33 shows in diagrammatic form all the information which has been made available in this article.

The time limit between Upper and Middle Eocene is



indicated on the diagram. The value of the evidence for the various small swings can be judged by the various well symbols which are explained in the legend.

The position of the coastline of the first "cycle" is to some extent artificial, as part of the coastal sediments have probably been removed by pre-Lower Fars erosion. The only area of control is between K-93 and K-76. South-eastwards and north-westwards the extension has been drawn parallel to the time line separating Middle from Upper Eocene. The resulting line marks therefore as closely as possible the position of the coast of the Upper Eocene shelf, which governed the position of the first reef sequence.

The time contact between the first and the second "cycle" is controlled only between K-94 and K-76. Extensions have again been drawn parallel to the time line separating Middle from Upper Eocene.

It should thus be well understood that the parallelism between these three lines is to some extent artificial.

The seaward edge of the lowest reef-potential area, coinciding by definition with the belt where fore-reef changes into off-shore facies (a transition zone, no doubt) is controlled in the area of Palani, where this change must take place (see Fig 30). It is also controlled in BH-3, where only a small thickness of lower fore-reef is present so that the line should go slightly seawards of this well. Finally, it is controlled between K-68 and K-85 where the change of facies can be marked on Fig 24. The curve of the edge of the shelf in the area of the southern dome of Qarah Chauq Dagh has been discussed above, and is necessitated by the facies distribution of the second reef "cycle." Whether the first reef "cycle" should be limited in a similar way is to some extent debatable.

The seaward edge of the shelf used by the second "cycle" should run somewhat more seawards than its lower equivalent. That is obvious from wells in the Tarjil area, where K-46 is on the shelf, showing still back-reef facies. It must also occur seawards of Azkand, where the second "cycle" already shows tongues of more off-shore sediment in its fore-reef. Finally, it should run far seawards of BH-3, where proper fore-reef is still present. The control on this shelf edge is therefore relatively weak, and there is no reason why it should not be shifted within the limits imposed upon it.

It may be noted that during the first "cycle" as well as during the second the shelf was broader in the north-west than in the south-east, and this tallies with findings from other sources. Facies lines therefore converge somewhat from north-west to south-east during the first two "cycles."

This principle would suggest that material from the third "cycle" should be found in the area of K-85, equivalent to what is found near Azkand. The fact that such is not the case proves that the facies lines controlling this third "cycle" cannot be parallel to the ones controlling the second "cycle." The point of crossing between the two sets is unknown, but it must occur between Bai Hassan and K-46, because the fourth well drilled on Bai Hassan and mentioned on p. 257 does show back-reef material of this third sequence, whereas, as stated, K-46 does not. A third point of observation, outside the area of investigation, some 40 km (25 miles) south-east of K-46, shows back-reef material of this third sequence also, and thus fixes the course of the coastline of this third "cycle" to some extent. The tracing of this line on Fig 33 is only one of several possible solutions.

The crossing of the landward edge of the shelf of the third "cycle" and the seaward edge of the shelf of the second "cycle" is therefore the result of the fact that the two groups of facies lines are not parallel.

It is possible to explain this sedimentologically. It has been demonstrated that the shelfs, on which the first two "cycles" were accommodated, become narrower and deeper towards the south-east. Therefore, each facies zone will become narrower from north-west to south-east. This decrease in width will persist in time until the discrepancy in depth between the shelf in the north-west and the south-east has disappeared, through sedimentary factors. From then on the facies lines will run parallel.

The disappearance of the discrepancy in width and depth was probably effected during the period of deposition of the first two "cycles," so that the facies lines of the third cycle must cross facies lines of previous "cycles," though the lines of the third "cycle" itself may well run parallel to each other.

Apart from the correlation mentioned on p. 257, Fig 32 also shows small discrepancies (presence of thin lower fore-reef in BH-3 and thicker off-shore sediments of the second "cycle" in K-85), which indicate that facies lines for the first and the second "cycles" and the line of section are not truly parallel and that the facies lines are not straight. The discrepancies, however, can be considered small, judging from the fact that the distance between Palani and K-85 is of the order of 80 km, 50 miles.

THE AGE OF THE "CYCLES" AND THEIR ROCK UNITS

The key to the age of the three "cycles" is found in the fauna occurring in the fore-reef facies of the third "cycle." *Miogypsinoides complanata* occurs together there with *Lepidocyclina* sp., an association identical with the faunal association of the Upper Oligocene in the south-western part of France.[12]

This would mean, although the foundation for this dating is admittedly weak, that the third "cycle" is of Upper Oligocene age. Without additional evidence it is assumed that the second "cycle" is of Middle Oligocene age, whilst the first one is dated as Lower Oligocene. It is not claimed that these datings coincide with the European subdivisions of the Oligocene in their type locality, and it will be noticed that in the diagrams the datings have been queried. There is at present no additional evidence to be found from the material examined for any other or any more precise dating.

It has been found convenient to refer to the various facies encountered in terms of rock units. Fig 34 gives the names in use. The following are their definitions:

Anah formation (Plate VIIIA and B). The actual type locality of this formation is about 9 miles east of the village of Nahiyah (latitude 34° 26′ 45″, longitude 41° 33′ 20″) on the Euphrates River. From there Ainsworth [1] described in 1838 a "formation of limestone with cerithiæ" which subsequent unpublished research by Dr F. R. S. Henson and the present author proved to be of sufficient importance to be considered as a rock unit.

de Boeck [2] mentions a "dolomitic limestone" of which the Anah limestone is without much doubt partly a synonym. Nicolesco [28] mentions the "Kara Tchauq Dagh Series," part of which is synonymous with the above formation. The same goes for Macovei's [27] "Calcaire de l'Euphrate," "Calcaire d'Asmari," and "Série d'Asmari." Henson [19] refers to this formation as "U. Oligocene limestone" and as "U. Oligocene—?Lower Miocene Miliola limestone."

As, however, the type locality of this formation occurs outside the area covered by this article it has been found convenient to consider an areal type locality within that region. Such a section occurs about 2½ miles N-43½°-E of the village of Ali Rash (latitude 36° 17′ 02″, longitude 37° 17′ 58″) on the southern dome of the Qarah Chauq Dagh.

The formation underlying the Anah limestone there is not exposed, but is without doubt the Azkand limestone (see below). Wherever else this formation occurs, the contact with the underlying formation is conformable, whereas the contact with the overlying rocks—Miocene limestones—is unconformable (these terms are used in the sense as defined by Rutten [29]).

A thickness of nearly 200 ft of generally white or grey dolomitized and recrystallized limestone occurs. This is massive in the lower part, but becomes thinner bedded higher up. The formation contains *Anthozoa*, *Bryozoa*, *Miogypsinoides complanata*, *Lepidocyclina* spp., and *Rotalia viennoti* Greig in the lower 45 ft. Upwards this is followed by about 23 ft of reef facies with *Anthozoa* and rare *Miogypsinoides complanata*, but probably without *Lepidocyclina* spp. Covering this are 120 ft of strongly recrystallized and dolomitized back-reef facies with rare *Miogypsinoides complanata*, *Austrotrillina howchini*, *Meandropsina anahensis* Henson, and indeterminable *Miliolidæ*. The age of this formation is considered to be ?Upper Oligocene.

The *Azkand formation* (Plate VIIIC) has its type locality on the north-east face of the Azkand Cirque, 3 miles N-65°-E from the village of Azkand (latitude 35° 43′ 58″, longitude 43° 37′ 25″) on the southern dome of the Qarah Chauq Dagh.

de Boeck's term "dolomitic limestone" [2] is partly synonymous with this formation name. It is possible that Nicolesco's "Kara Tchauq Dagh Series" [28] and Macovei's "Calcaire d'Asmari," "Calcaire de l'Euphrate," and "Série d'Asmari" are also partly synonymous.[27]

This formation covers the Baba limestone (see below) conformably though regressively, and in its turn is covered by the Anah limestone as mentioned above. It has never been found covering the Bajawan formation (see below), but it is theoretically possible that it covers somewhere the Tarjil formation (see below).

A thickness of 340 ft of generally massive dolomitic limestone shows *Rotalia viennoti*, *Heterostegina cf assilinoides* Blanckenhorn, *Miogypsinoides complanata* joined by *Lepidocyclina* spp. in the lower 250 ft only. The age is probably also ?Upper Oligocene, as the formation forms the fore-reef facies of the Anah formation.

The *Bajawan formation* (Plate VIIIA) finds its type locality in well K-109 on the Baba dome of the Kirkuk structure. It is named after the village Bajawan, which occurs in that area. The co-ordinates of K-109 are: latitude 35° 33′ 08″ and longitude 44° 18′ 55″. This rock unit is synonymous with part of Nicolesco's "Kara Tchauq Dagh Series" [28] and with part of Macovei's "Calcaire d'Asmari," "Calcaire de l'Euphrate," and "Serie d'Asmari." [27] The formation also forms part of Barber's [8] "Qarah Chauk Group" as well as part of his "Miliola and reef limestones." Henson [19] refers to it as "U. Oligocene Miliola limestone," "Oligocene Miliola limestone," "Oligocene limestone," and "Miliola limestone." Finally, it is synonymous with Daniel's [10] MR/2.

Underlying the Basal Fars Conglomerate (see p. 233), which is transgressive, it overlies the Baba limestone (see below) conformably. A thickness of 128 ft consists of an alternating sequence of tight cream coloured back-reef miliolid limestone and more porous patchily dolomitized rotalid-algal reef limestone with fairly abundant coral fragments. The reef beds become thicker and more abundant towards the base of the formation. The fauna comprises *Miliolidæ* spp. indet., *Praerhapidionina delicata*, *Archaias kirkukensis*, *Peneroplis thomasi*, *Peneroplis evolutus*, *Austrotrillina howchini*, *Corallinacea*, *Bryozoa*, and *Anthozoa*.

The age of this formation is most likely to be ?Middle Oligocene, but true evidence lacks.

The *Baba formation* (Plate VIIB) has its type locality again in K-109, and is named after the village of Baba Gurgur, which also gave the Baba dome its name.

Again synonymity must be accepted with part of Nicolesco's "Kara Tchauq Dagh Series" [28] and with part of Macovei's "Calcaire d'Asmari," "Calcaire de l'Euphrate," and "Serie d'Asmari." de Boeck [2] refers to its equivalent as "rubbly limestone" [2, p. 65] and as "limestones containing *Lepidocyclina cf formosa*." [2, p. 94] Without much doubt, this formation is also part of Barber's [8] "Nummulite limestone" and of his "Qarah Chauk Group." It is also synonymous with Daniel's FO/2.[10]

The formation is covered conformably by the Bajawan formation in its type locality, but elsewhere in the area may be covered regressively by the aforementioned Azkand formation or Anah formation. It

FIG. 31- ABBREVIATED RANGE CHART OF PART OF THE PRE-MIOCENE STRATIGRAPHY OF BH-3

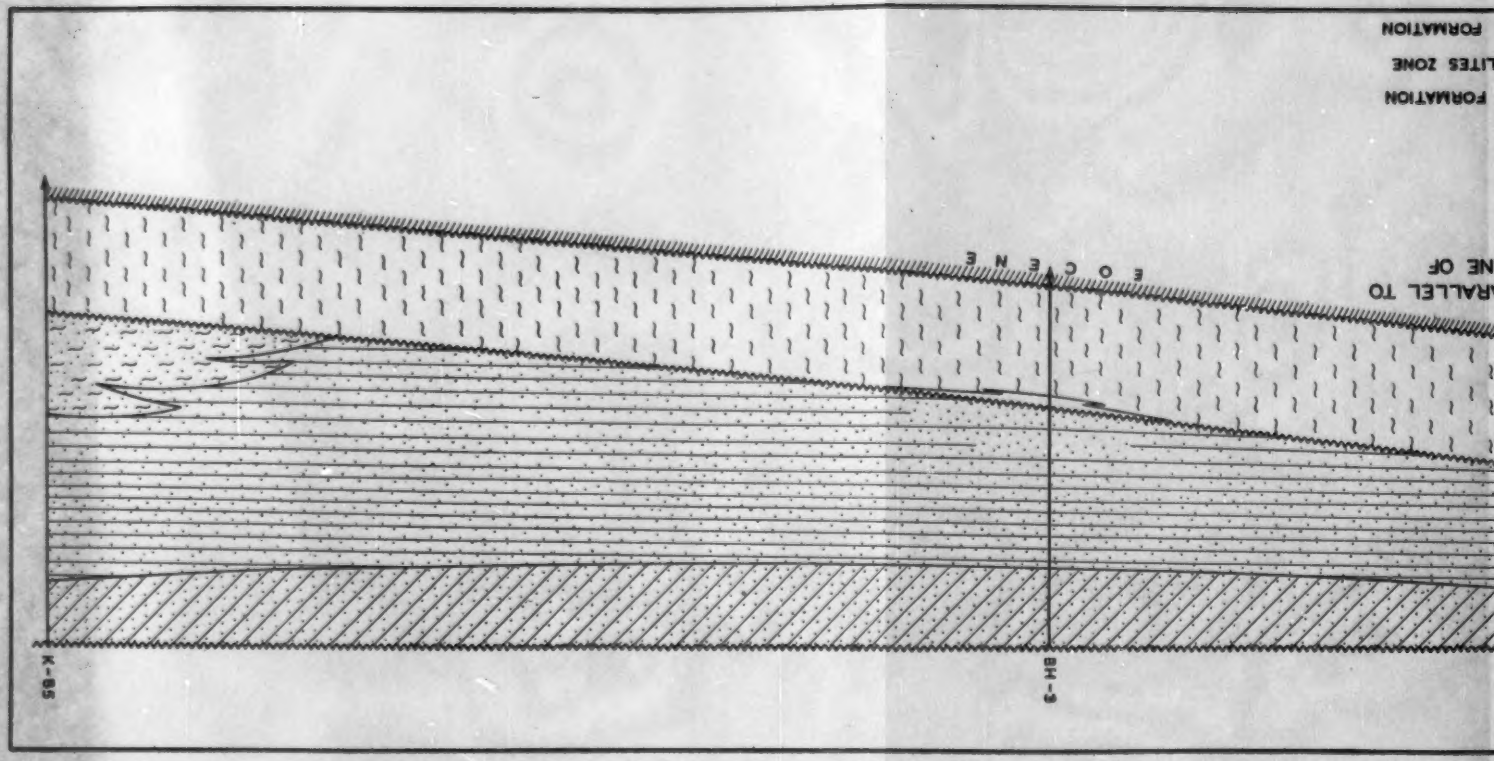
Depths given are those below the base of the Lower Fars Conglomerate	ROCK UNIT	FACIES	FAUNI-ZONE	AGE
0' 10' 25' 31' 33' 36' 41' 47' 53' 56' 59' 65' 69' 76' 79' 86' 90' 95' 101' 106' 108' 113' 126' 131' 136' 141' 144' 149' 153' 156' 167' 171' 175' 180' 185' 190' 198' 203' 208' 213' 216' 221' 226' 234' 239' 245' 249' 253' 258' 263' 271' 276' 281'	BAJAWAN LIMESTONE FORMATION	BACK-REEF-REEF	KIRKUKENSIS ZONE	? MIDDLE OLIGOCENE

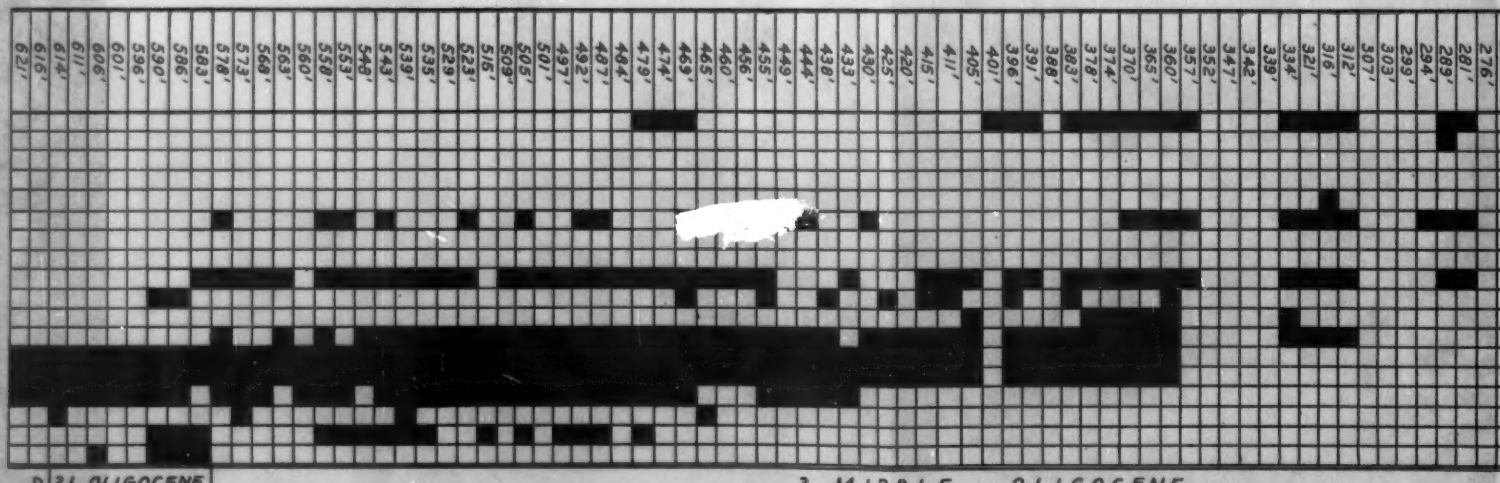
Rotalia viennoti
Reef corals
Archaias sp.
Miliolidae
Austrotrillina howchini
Amphistegina sp.
Archaias kirkukensis
Borelis pygmaea
Lepidocyclina sp.
Eorupertia sp.
Heterostegina sp.
Operculina sp.
Globigerina spp.
Smaller foraminifera indet.
Cibicides spp.
Haplophragmium slingeri
Nummulites spp.
Glauconite

FIG. 32 SECTION APPROXIMATELY PARAL
FACIES LINES OF THE OLIGOCENE
PALANI, BH-3 & K-85

SCALES
HORIZONTAL 0 1 2 3 Miles
VERTICAL 0 1000 2000 Feet

LEGEND
KIRKUKENSIS ZONE
LEPIDOCYCLINA ZONE
LEP./NUMM. ZONE
TARJIL FOR
NUMMULITES
PALANI FOR





OFF-SHORE	? L. OLIGOCENE	? MIDDLE OLIGOCENE
	NUMM. ZONE	NUMMULITES / LEPIDOCYCLINA ZONE — LEPIDOCYCLINA ZONE
	OFF-SHORE FORE-REEF	FORE - REEF
	SH. ALAS FORM.	BABA LIMESTONE FORMATION

overlies the Shurau formation transgressively, but may elsewhere overlie the Tarjil formation conformably (see below).

Sixty-five ft of porous dolomitized limestone contain *Nummulites intermedius-fichteli*, *Nummulites* spp., *Operculina* sp., rare *Lepidocyclina* spp., and rare *Bryozoa*. Elsewhere all *Nummulites* spp. may be absent, and more *Lepidocyclina* spp. may occur together with *Rotalia viennoti* and occasional *Heterostegina cf assilinoides*.

It is probable that the age of the formation is ?Middle Oligocene. The unit forms the fore-reef equivalent of the Bajawan limestone.

The *Tarjil formation* has its type locality in K-85, which is situated at latitude 35° 26′ 42″ and longitude 44° 25′ 28″. It gets its name from the village of Tarjil, which also named the Tarjil plunge, on which it is located.

The formation is part of what Baker (Henson) [7] calls "globigerinal limestones and marls," whereas Barber's [8] "Globigerina limestone" and "Qarah Chauk Group" are also partly equivalent with it. Daniel's [10] GO/2 is synonymous with it as well.

It underlies in its type locality the Baba formation conformably, but elsewhere may occur below the Azkand formation or below an as yet undefined and undetected off-shore equivalent thereof, both of which will in that case cover it conformably though regressively.

In its type locality it overlies the Palani formation (see below), from which it is separated by a stratigraphic break marked by glauconite.

Its thickness of some 250 ft consists entirely of slightly dolomitized globigerinal marly limestone, of which the fauna has as yet not been analysed properly. The formation is probably of ?Middle Oligocene age and forms the off-shore equivalent of the Baba formation, which, in its turn, is the fore-reef equivalent of the Bajawan limestone.

The *Shurau formation* (Plate VIA) has again been defined from K-109 and has been named after the village of Shurau on the Baba dome (latitude 35° 30′ 03″, longitude 44° 22′ 45″).

Again this formation forms part of Nicolesco's "Kara Tchauq Dagh Series" and of Macovei's three units. Henson [10] refers to it as "L.-M. Oligocene Miliola limestones," and the formation is also partly equivalent to his "Lower Reef Limestones." Grimsdale [16] mentions "Miliola limestone," which is also synonymous. Barber [8] gives "Miliola and reef limestones," part of which is synonymous with this formation. The same is true for his "Qarah Chauk Group." Daniel's [10] MR/1 again is synonymous with this formation.

In K-109 it is covered conformably but transgressively by the Baba formation, but elsewhere the Bajawan formation may cover it in the same way. It overlies in its turn conformably the Sheikh Alas formation (see below), but may elsewhere lie directly on Eocene.

A thickness of 60 ft consists of about 18 ft of grey dense flocculitic limestone with abundant miliolids, rare *Rotalia viennoti*, and a few *Algæ*, and 42 ft of porous coralline reef limestone with *Dendrophyllum cf gurgurdanensis* with back-reef intercalations at the top. *Austrotrillina howchini*, *Austrotrillina paucialveolata*, *Archaias operculiniformis*, and miliolids occur as well.

The age is probably ?Lower Oligocene, but this could not be proved by fossils.

The *Sheikh Alas formation* (Plate VIB) has its type locality about 800 yd N-252°-E of the village of Sheikh Alas (latitude 35° 54′ 38″, longitude 43° 35′ 30″) on the northern dome of the Qarah Chauq Dagh, where this formation occurs in outcrop. It is more widely distributed in the wells on the Kirkuk structure, however.

Shurau formation covers this formation conformably. Elsewhere Baba formation occurs conformably but transgressively on top of it. In its type locality Sheikh Alas formation covers Eocene shoal limestones, but elsewhere it may cover the Palani formation (see below) conformably.

The formation is synonymous to part of Nicolesco's "Kara Tchauq Dagh Series" [28] and to part of Macovei's three units mentioned repeatedly above. de Boeck *et al.* mention "limestones with *N. intermedius-fichteli*," [2,p.94] which, without much doubt, are equivalent to this formation. The same is true for part of Barber's [8] "Nummulite limestone" and "Qarah Chauk Group." Daniel's FO/1 [10] is also synonymous.

Eighty-five ft of dolomitic and recrystallized generally porous and occasionally rubbly limestone contains obscured *Nummulites fichteli-intermedius* and some indeterminable radiate *Nummulites* spp. Elsewhere fragments of indeterminable rotalids occur with *Dendrophyllum cf gurgurdanensis*.

This formation is the fore-reef equivalent of the Shurau formation, and is probably of ?Lower Oligocene age.

The *Palani formation* with its type locality in K-85 on the Tarjil plunge again but named after the village of Palani (latitude 35° 49′ 15″, longitude 43° 35′ 30″) on the northern dome of the Qarah Chauq Dagh, where the formation occurs in outcrop (though strongly recrystallized and alternating with fingers of Sheikh Alas formation), overlies Eocene in all cases but underlies Sheikh Alas formation conformably or is separated from an overlying Tarjil formation by a transgression marked by glauconite.

The formation is synonymous with part of Baker's (Henson's) "globigerinal marly limestones and marls." [7] It is also equivalent to part of Barber's [8] "Globigerina limestone" and of his "Qarah Chauk Group." Daniel's GO/1 is also synonymous.[10]

It consists of 210 ft of somewhat dolomitized globigerinal marly limestone, very similar to that of the Tarjil formation. It is probably of ?Lower Oligocene age and is the off-shore equivalent of the Sheikh Alas formation. Its fauna has not yet been analysed. Plate VIC illustrates a typical example.

These eight formations form together the Kirkuk

group, which should also include an as yet undiscovered or unidentified off-shore equivalent of the Anah–Azkand formation if subsequently found. This group can be defined as a sequence of reef-controlled sediments of Oligocene age in which three separate reef "cycles" can be distinguished. The first two are separated by a transgression, the last covers the second after a regression. Palæontologically a number of faunizones can be defined in some of the formations which have been dealt with more extensively above.

This group as such is partly synonymous with Nicolesco's "Kara Tchauq Dagh Series,"[28] Macovei's "Calcaire d'Asmari," "Calcaire de l'Euphrate," and "Serie d'Asmari,"[27] and with Barber's "Qarah Chauk Group."[8] All these older terms, however, cover, apart from the genetically logical Kirkuk group, other formations of Eocene and Miocene age, which makes retaining of these terms inadvisable. The formations themselves are all clearly mappable in the field which allows them to be raised in fact.

FIG. 34: TIME- ROCKUNIT AND FAUNI-ZONE STRATIGRAPHY OF THE OLIGOCENE OF THE KIRKUK, BAI HASSAN AND QARAH CHAUQ DAGH AREA

AGE	FACIES	REEF/BACK-REEF	FAUNI-ZONES	FORE-REEF	FAUNI-ZONES	OFF-SHORE/GLOBIGERINAL	
OLIGOCENE	UPPER	ANAH LIMESTONE FORMATION	MIOGYPSINOIDES	AZKAND LIMESTONE FORMATION	MIOGYPSINOIDES MIOGYPSINOIDES/ LEPIDOCYCLINA	NOT KNOWN	KIRKUK-GROUP
	MIDDLE	BAJAWAN LIMESTONE FORMATION	KIRKUKENSIS DELICATA	BABA LIMESTONE FORMATION	LEPIDOCYCLINA LEPIDOCYCLINA/ NUMMULITES	TARJIL FORMATION	
	LOWER	SHIRAU LIMESTONE FORMATION	DENDROPHYLLUM PAUCIALVEOLATA	SHEIKH ALAS LIMESTONE FORMATION	NUMMULITES	PALANI FORMATION	

CONCLUSIONS AND FINAL REMARKS

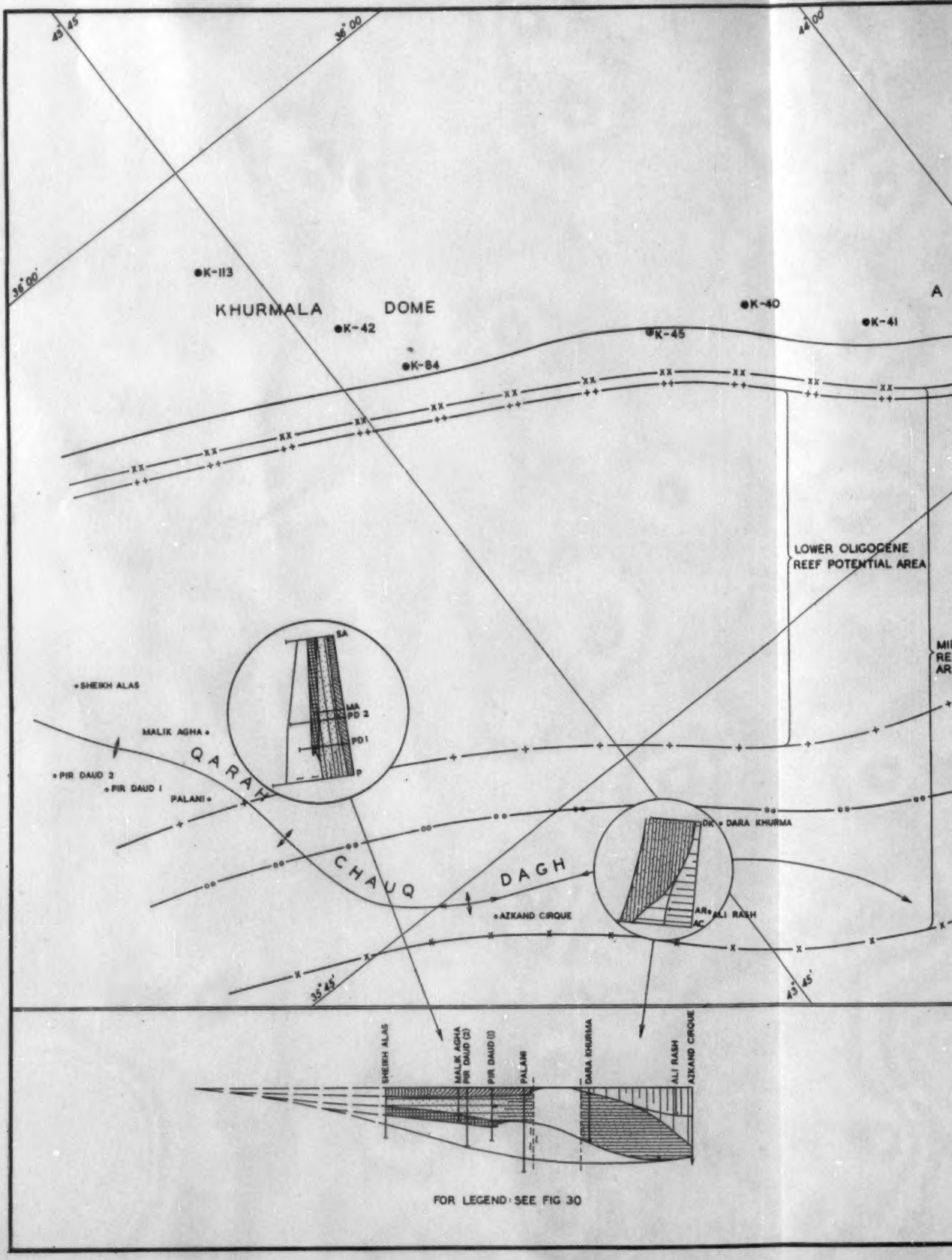
The existence of an Oligocene reef-potential area striking between N-110°-E and N-120°-E (with local variations) must be accepted. Its width varies between roughly 20 km (12·5 miles) in the NW. to some 16 km (10 miles) in the central area and to again some 20 km (12·5 miles) in the SE.

This reef belt first became inhabited by reef-forming organisms when an Upper Eocene regression brought the sea floor to optimum level. There is slight evidence in the existence of a basal Oligocene conglomerate in K-86 only that there might have been a small basal Oligocene transgression prior to the reef formation. Stabilization decreased the reef-potentiality at any one place and forced the reef to seek optimum water depth farther and farther from land, thereby compelling it to grow over its own fore-reef and permitting behind it the development of a lagoonal back-reef facies.

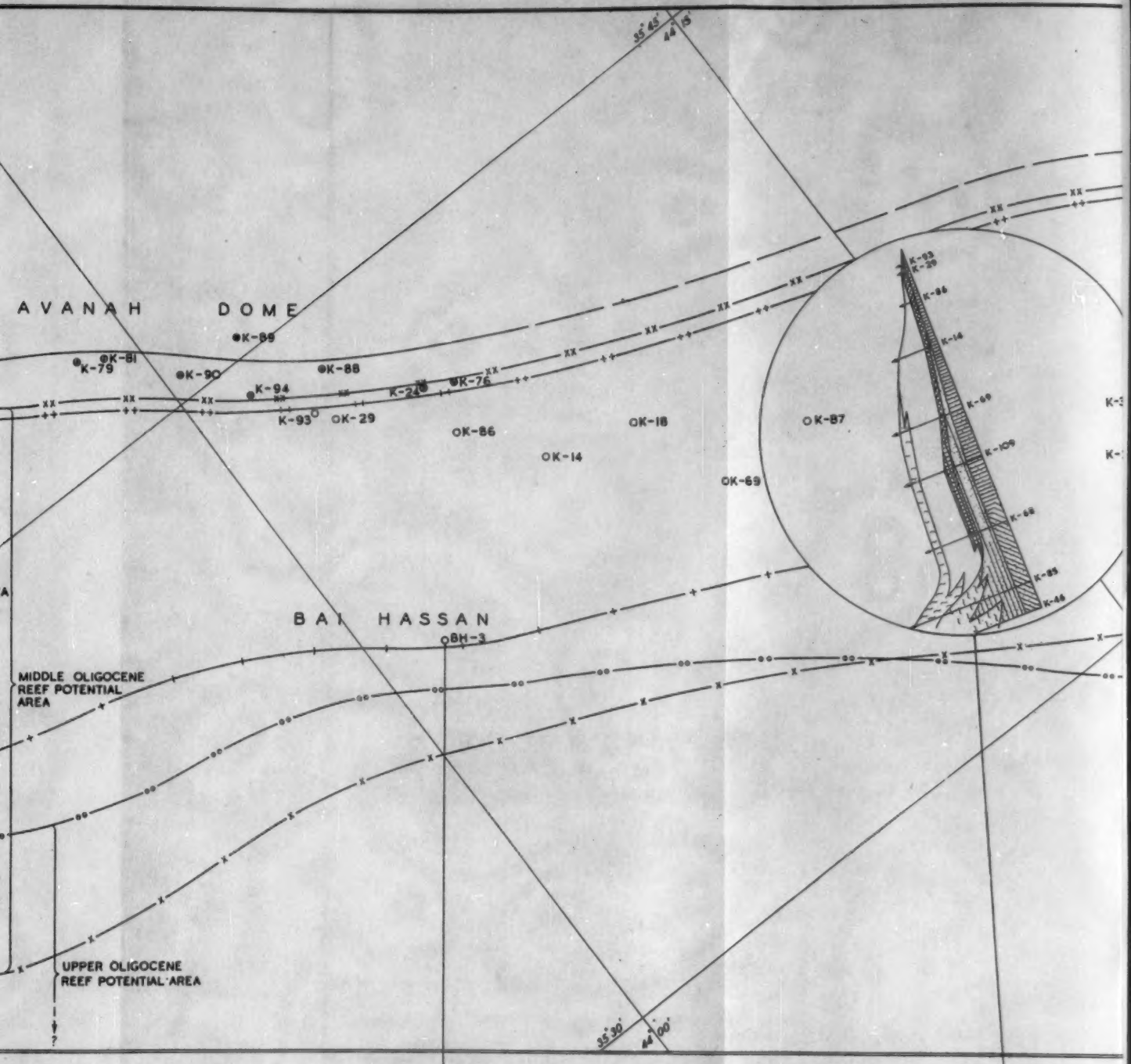
At the end of the ?Lower Oligocene the reef-potential area was filled up and additional reef-growth became possible only after a transgression re-created a reef-potential area by deepening of the sea (and drowning of the former reef deposits) near the original shore. This second ?Middle Oligocene reef development was cut short at the end of the ?Middle Oligocene by withdrawal of the sea.

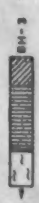
The regression at the end of the ?Middle Oligocene resulted in emergence of practically the entire ?Middle Oligocene reef-potential area. The result was a new coastline. The position and direction of this ?Upper Oligocene coastline was directly dependent on the slope of the ?Middle Oligocene shelf. Where this was steeper, in the south-east, the coastline was close to the edge of the ?Middle Oligocene shelf. Where it was less steep, in the north-west, the coastline was farther away from that edge. The coastline in the south-east lies south-west of the Tarjil plunge, but evidence exists in adjoining areas that such a coastline did indeed exist. Renewed—?Upper Oligocene—reef formation took place along that coastline. Fig 33 shows the extent of the original reef-potential area, which coincides approximately with the ?Lower Oligocene reef belt. The ?Middle Oligocene reef belt extended farther seawards (the ?Lower Oligocene fore-reef having shallowed that area) as well as farther landwards (owing to the transgression). The ?Upper Oligocene reef did extend farther seawards because of the shallowing due to the ?Middle Oligocene fore-reefs, but it did not extend as far landwards as the ?Middle Oligocene because of its origin after a regression.

Finally, it is of interest to be somewhat more detailed about the position and extent of the transgression between the ?Lower and the ?Middle Oligocene. It was found that the ?Middle Oligocene reef "cycle" was very likely deposited under tectonically stable conditions. Nevertheless, it was postulated that a transgression separated it from the ?Lower Oligocene. A somewhat unusual configuration is argued therefore, that the effect of the actual transgression which "triggered" the ?Middle Oligocene reef "cycle" was finished before the reef started growing again. Thus, the transgression itself was of relatively short duration and stable conditions replaced the downward movement after only a relatively short length of time.

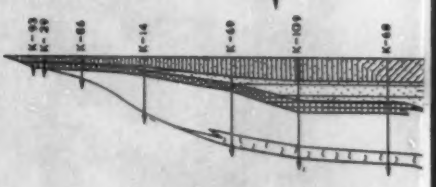


FOR LEGEND SEE FIG 30

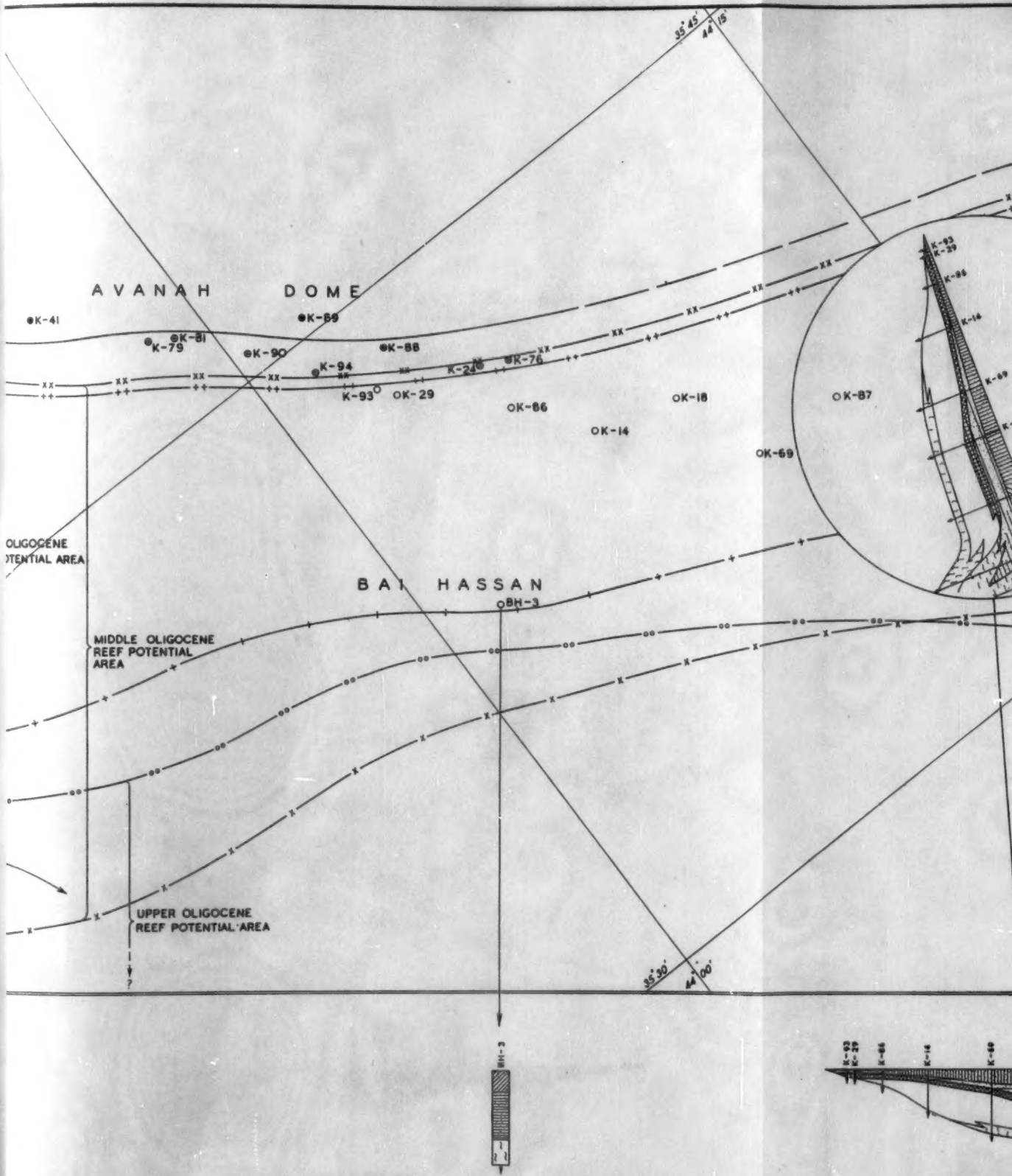


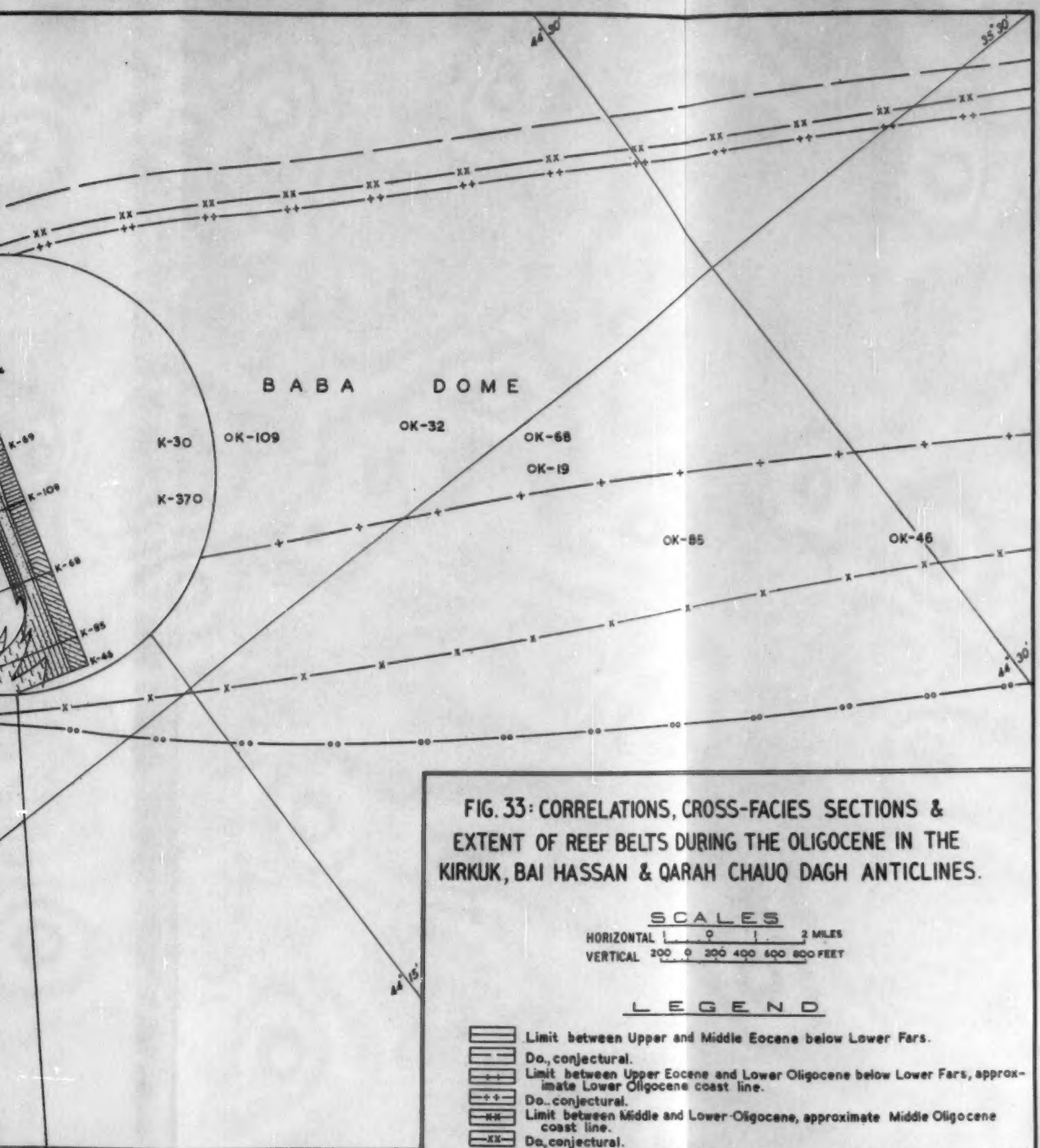


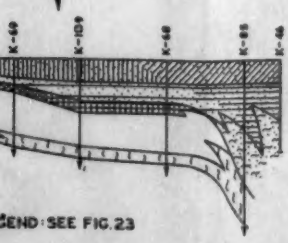
FOR LEGEND SEE FIG. 32



FOR LEGEND SEE FIG. 23


35°45'
44°15'
AVANAH DOME
K-41
K-89
K-81
K-79
K-90
K-88
K-94
K-24
K-76
K-93
OK-29
OK-86
OK-18
OK-87
OK-14
OK-69
OLIGOCENE
TENTIAL AREA
BAI HASSAN
BH-3
MIDDLE OLIGOCENE
REEF POTENTIAL
AREA
UPPER OLIGOCENE
REEF POTENTIAL AREA
35°30'
44°00'
FOR LEGEND SEE FIG. 32
FOR LEGEND





GEND : SEE FIG. 23

FIG. 33: CORRELATIONS, CROSS-FACIES SECTIONS & EXTENT OF REEF BELTS DURING THE OLIGOCENE IN THE KIRKUK, BAI HASSAN & QARAH CHAUQ DAGH ANTICLINES.

SCALES

HORIZONTAL 0 1 2 MILES

VERTICAL 200 0 200 400 600 800 FEET

LEGEND

- Limit between Upper and Middle Eocene below Lower Fars.
- Do., conjectural.
- Limit between Upper Eocene and Lower Oligocene below Lower Fars, approximate Lower Oligocene coast line.
- Do., conjectural.
- Limit between Middle and Lower Oligocene, approximate Middle Oligocene coast line.
- Do., conjectural.
- Seaward limit of the Lower Oligocene reefpotential area coinciding approximately with the change from fore-reef deposits into off-shore sediments.
- Do., conjectural.
- Seaward limit of the Middle Oligocene reefpotential area coinciding approximately with the change from fore-reef deposits into off-shore sediments.
- Do., conjectural.
- Limit between Upper and Middle Oligocene, approximate Upper Oligocene coast line.
- Do., conjectural.
- ● Well with Middle Eocene below Lower Fars.
- ◉ Well with Upper Eocene below Lower Fars.
- ◉ Well with ? Middle Oligocene on Eocene.
- ○ Well with ? Lower Oligocene on Eocene.

There are, in fact, some arguments for this idea:

A transgression during the ?Middle Oligocene would produce a more or less continuous sheet of conglomerates below the ?Middle Oligocene "cycle." But a transgression of limited duration between the "cycles" would produce only a conglomerate near the coast. The mid-Oligocene conglomerates found are confined to the area between wells K-18 and K-93, the coastal area in fact.

It is correct to say that it is possible that conglomerates which are found marginally may change their facies seawards into unrecognizable material. In the present case that argument cannot hold. If indeed the ?Middle Oligocene was slowly transgressive, at any one moment a conglomerate will be formed along the then strand-line. Because the strand-line shifts upshore, the conglomeratic belt will do likewise. At the end of the transgression therefore a complete conglomeratic "sheet" will underlie the subsequent deposits. No such conglomeratic layer was found. It is therefore assumed that there is none, and that assumption is made with some reason because of the many points of observation. Evidence of a transgression during the ?Middle Oligocene sequence is therefore non-existent, whereas the evidence which does exist points clearly to a transgression between the two "cycles." However, the argument based on the distribution of these conglomerates is weak because in general they are thin, and consequently they may have been swept away by subsequent wave action.

There is a faunal argument as well which is of somewhat more value. If the transgression occurred during the ?Middle Oligocene it is to be expected that the younger sediments encroach farther upon the land than the older ones. Thus, the *Dendrophyllum* zone and the *kirkukensis* zone should reach farther towards the north-west than the *paucialveolata* zone and the *delicata* zone. In the fore-reef facies the *Lepidocyclina–Nummulites* zone (it is known that the *Lepidocyclina* zone is younger than the *Lepidocyclina–Nummulites* zone from BH-3, where the first occurs on top of the second, see p. 257).

It can be seen from the various diagrams that that is not the case. It is agreed that removal of the top of each "cycle" by subsequent transgression of part or all of the *kirkukensis* and *Dendrophyllum* zones may produce the present configuration. But that does not apply to the distribution of the fore-reef zones. At all times, the fore-reef zones were protected against erosion by the overlying back-reef. And the palæontological stratigraphy of the fore-reef of the ?Middle Oligocene sequence does not show the younger strata to reach farther towards the north-west than the older ones. This configuration must be primary, and cannot be the result of erosion or any other action of subsequent factors.

A final argument is the succession within the ?Middle Oligocene, which shows clearly an emigrating reef with a back-reef of generally less than 100 ft thickness (see p. 247).

The stratigraphy within the ?Middle Oligocene therefore suggests deposition of the younger strata farther away from the shore than the older strata. Such stratigraphy cannot be reconciled with deposition under transgressive conditions.

Nevertheless, there is strong evidence for a transgression below sediments of the ?Middle Oligocene sequence. The conclusion, inevitably, must be that the effects of that transgression had worn off when the reef started growing again during the ?Middle Oligocene.

ACKNOWLEDGMENTS

This paper is published by permission of the management and the Chief Geologist of the Iraq Petroleum and Associated Companies Ltd.

Numerous geologists have expressed opinions on the stratigraphy of the Main Limestone ever since the structure started producing twenty-nine years ago. The writer has drawn freely upon unpublished work of many of them, too many to mention individually. However, reference must be made to Dr F. R. S. Henson, Senior Research Geologist of the Iraq Petroleum Company; H. V. Dunnington, the Research Palæontologist; and J. McGinty, now Senior Geologist of the associated Qatar Petroleum Company. Dr A. H. Smout took the photographs incorporated in the article. To all these the author offers his sincere thanks.

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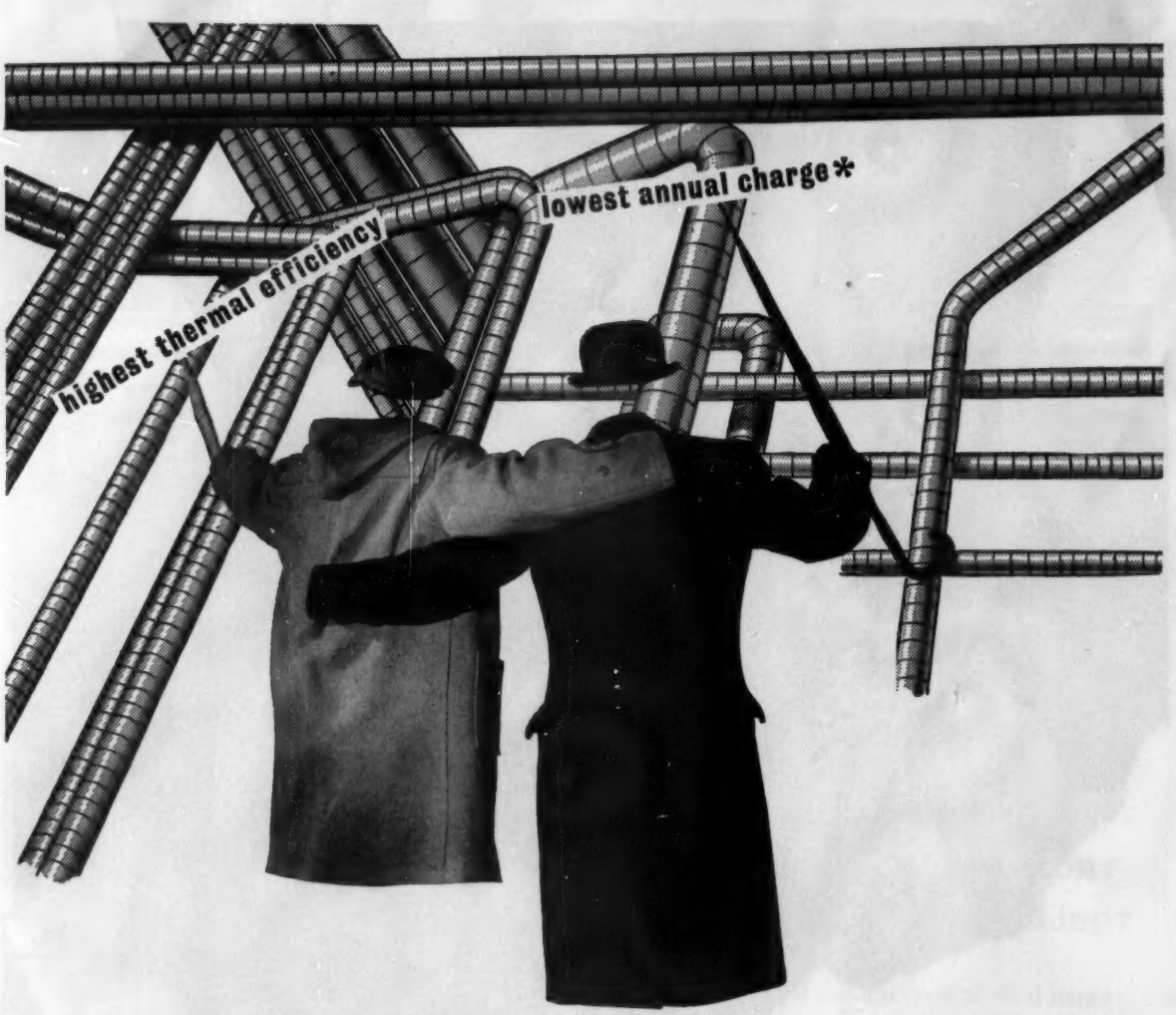

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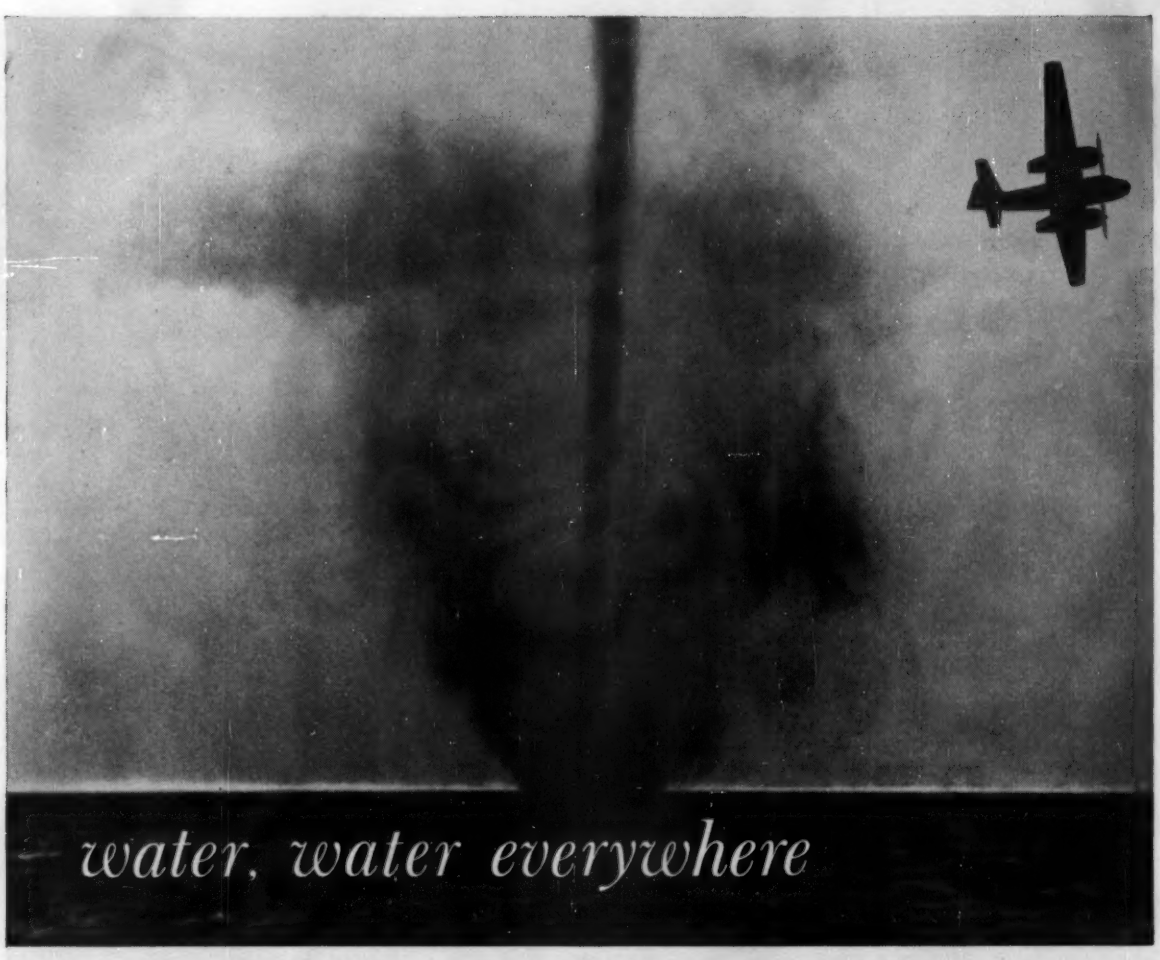

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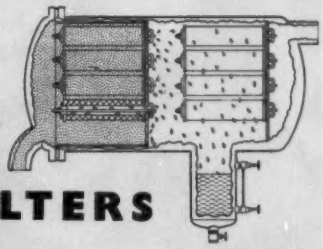

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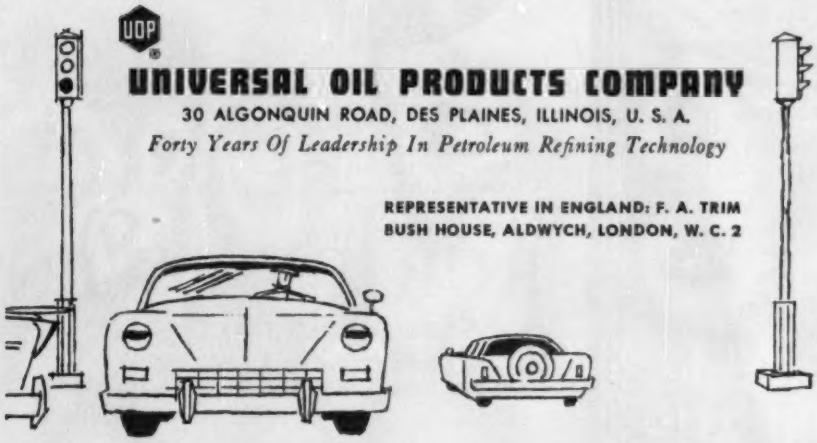

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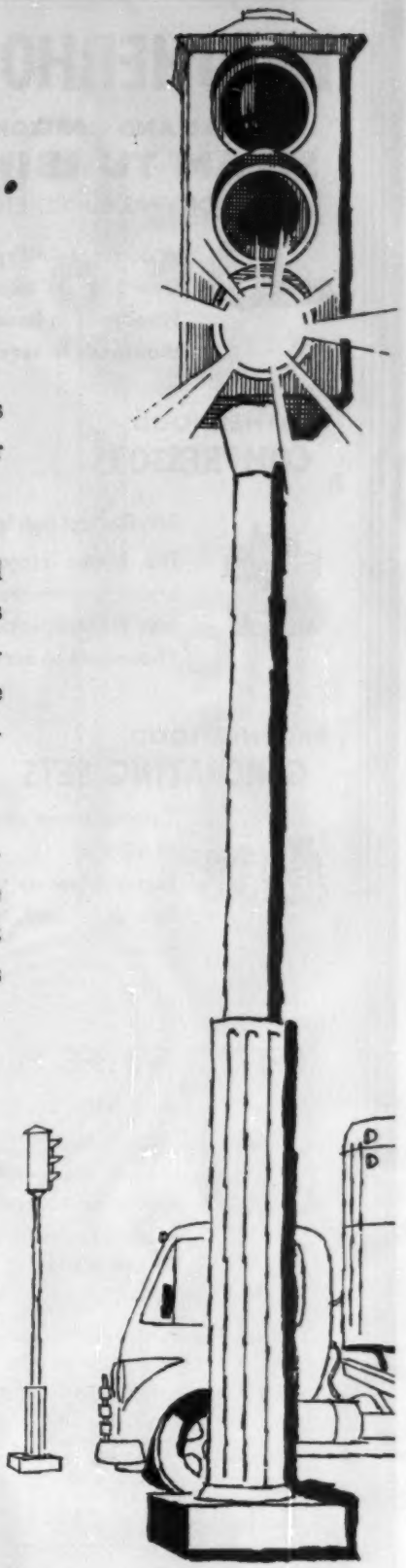

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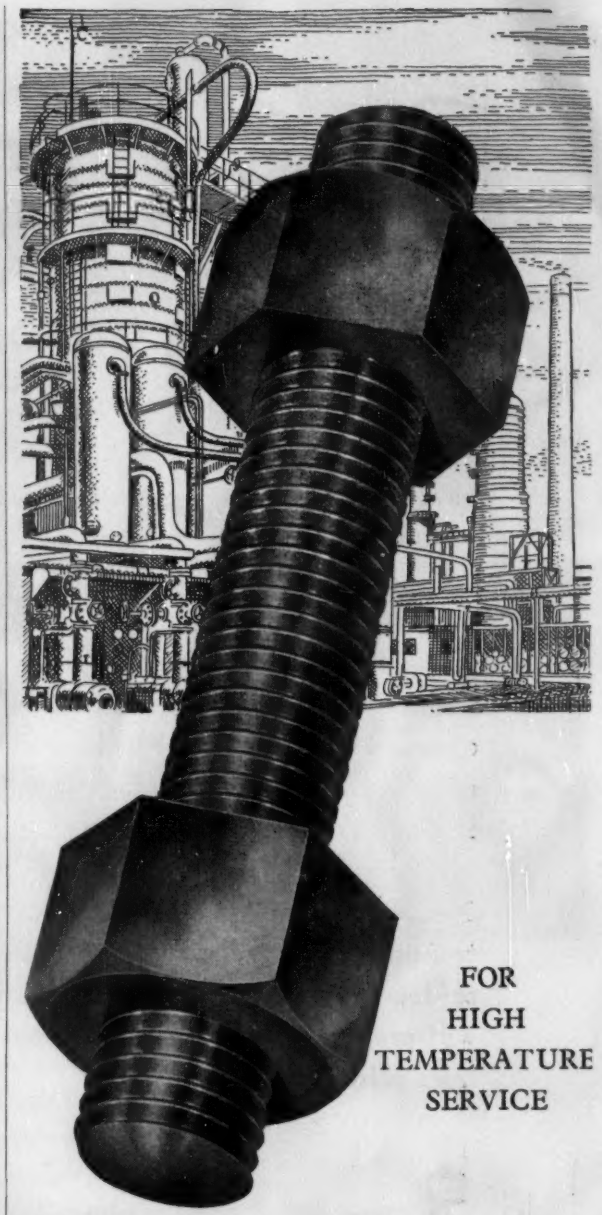

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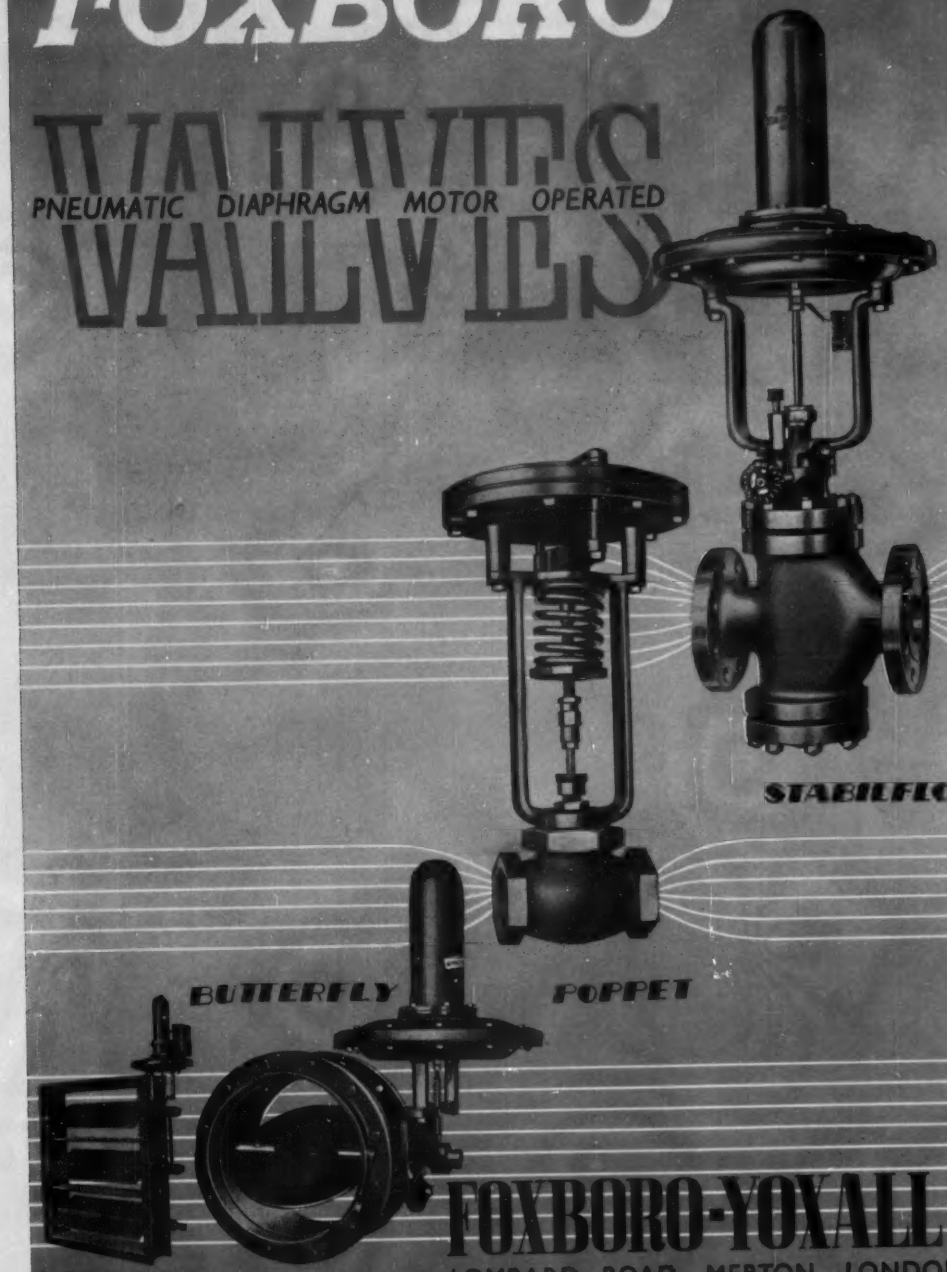

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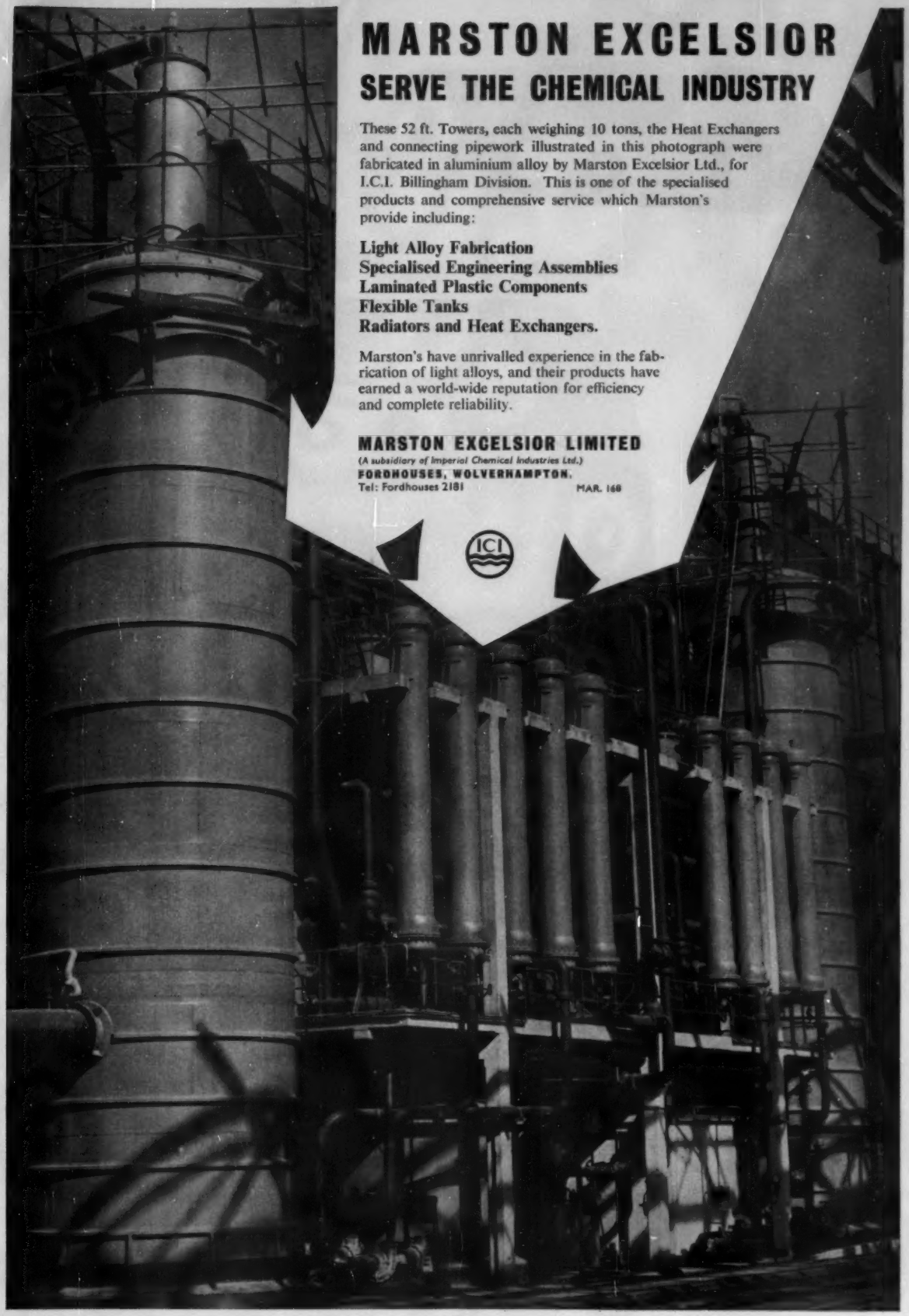

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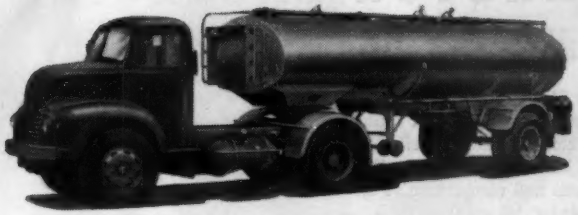

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